

PROCEEDINGS OF THE FAO CONFERENCE ON FISH BEHAVIOUR
IN RELATION TO FISHING TECHNIQUES AND TACTICS

ACTES DE LA CONFÉRENCE FAO SUR LE COMPORTEMENT DU POISSON
EN FONCTION DES TECHNIQUES ET TACTIQUES DE PÊCHE

ACTAS DE LA CONFERENCIA DE LA FAO SOBRE EL COMPORTAMIENTO DE LOS PECES
EN RELACION CON LAS TECNICAS Y TACTICAS PESQUERAS

Bergen, Norway, 19-27 October 1967

Bergen, Norvège, 19-27 octobre 1967

Bergen, Noruega, 19-27 octubre 1967

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ORGANISATION DES NATIONS UNIES POUR L'ALIMENTATION ET L'AGRICULTURE
ORGANIZACION DE LAS NACIONES UNIDAS PARA LA AGRICULTURA Y LA ALIMENTACION
ROME, 1969

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Noruega, Bergen, 19-27 octubre 1967

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VOLUME III - EXPERIENCE PAPERS

VOLUME III - COMPTES RENDUS D'EXPERIENCES

VOLUMEN III - DOCUMENTOS DE EXPERIENCIAS

FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS
ORGANISATION DES NATIONS UNIES POUR L'ALIMENTATION ET L'AGRICULTURE
ORGANIZACION DE LAS NACIONES UNIDAS PARA LA AGRICULTURA Y LA ALIMENTACION

Rome, November 1969

Rome, novembre 1969

Roma, noviembre 1969

PREPARATION OF THIS VOLUME

This is the third and final volume of the Proceedings of the FAO Conference on Fish Behaviour in Relation to Fishing Techniques and Tactics and contains the last of the experience papers contributed to the Conference.

The first volume contains the report of the Conference, list of contributions and list of participants; the second volume contains the review papers and the first of the experience papers contributed to the Conference.

The views expressed in the contributions are those of the authors and not necessarily of the Food and Agriculture Organization of the United Nations.

In addition to the editors the following persons helped to prepare this volume: Dr. (Mrs.) E. Clarke, Mr. S. Olsen and Biological Data Section, Fishery Resources and Exploitation Division.

PREPARATION DE CE VOLUME

Ce tome est le troisième et dernier des Actes de la Conférence FAO sur le Comportement du Poisson en Fonction des Techniques et Tactiques de Pêche il comprend les derniers comptes rendus d'expériences présentés à la Conférence.

Le premier tome comprend le rapport de la Conférence, la liste des contributions et celle des participants; le second tome comprend les études spécialisées et les premiers comptes rendus d'expériences présentés à la Conférence.

Les vues exprimées dans les contributions sont celles des auteurs et pas nécessairement celles de l'Organisation des Nations Unies pour l'alimentation et l'agriculture.

MM. E. Clarke et S. Olsen et la Section des données biologiques de la Division des ressources et de l'exploitation des pêches ont participé à la préparation du présent volume.

PREPARACION DE ESTE VOLUMEN

Este es el tercero y último volumen de las Actas de la Conferencia de la FAO sobre el Comportamiento de los Peces en Relación con las Técnicas y Tácticas Pesqueras y contiene los últimos documentos de experiencias presentados a la Conferencia.

El primer volumen contiene el informe de la Conferencia, lista de contribuciones y lista de participantes; el segundo volumen contiene los documentos de reseña y el primero de los documentos de experiencias presentados a la Conferencia.

Las opiniones expresadas en los documentos y en los informes son las de los autores y participantes y no necesariamente las de la Organización de las Naciones Unidas para la Agricultura y la Alimentación.

Este volumen ha sido preparado bajo la Sección de Datos Biológicos de la Dirección de Recursos Pesqueros y Explotación con la colaboración de: Dr. E. Clarke, Mr. S. Olsen.

Distribution

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Ben-Tuvia, A. and W. Dickson 16-1B008
(1969)
FAO Fish.Rep., (62)Vol.3:422 p.
Proceedings of the FAO Conference on
Fish Behaviour in Relation to Fishing
Techniques and Tactics, Bergen, Norway,
19-27 October 1967. Volume 3. Experience
papers
Actes de la Conférence FAO sur le
comportement du poisson en fonction des
techniques et tactiques de pêche, Bergen,
Norvège, 19-27 octobre 1967. Volume 3.
Comptes rendus d'expériences
Actas de la Conferencia de la FAO sobre
el Comportamiento de los Peces en
Relación con las Técnicas y Tácticas
Pesqueras, Bergen, Noruega, 19-27 octubre
1967. Volumen 3. Documentos de
experiencias

Clupeidae. Engraulidae. Gadidae.
Scorpaenidae. Thunnidae. Soleidae.
Field observations - catch methods.
Physiology. Application of observations
in designing fishing gear.
Co 16-1B006. Pr 10-195me.

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VISUAL ACUITY OF YELLOWFIN TUNA, Thunnus albacares

by

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U.S. Bureau of Commercial Fisheries Biological Laboratory
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Abstract

Yellowfin tuna, Thunnus albacares, were trained to respond differently to images of vertical stripes and horizontal stripes. The luminance of the image was reduced until the fish was unable to distinguish vertical from horizontal stripes. Visual acuity was calculated from the width of the stripes and the distance from which the fish made its discriminations. The maximum visual acuity of yellowfin tuna was 0.274, compared with 0.180 for skipjack tuna, Katsuwonus pelamis, and 0.135 for little tunny, Euthynnus affinis. The corresponding minimum visual angles were 3.65, 5.56, and 7.41 minutes.

ACUITE VISUELLE DE L'ALBACORE (Thunnus albacares)Résumé

Des albacores (Thunnus albacares) ont été conditionnés à réagir différemment à l'image de bandes verticales et à celle de bandes horizontales. La luminance de l'image a été abaissée jusqu'à ce que le poisson ne puisse plus distinguer entre les deux sortes de bandes. L'acuité visuelle a été calculée sur la base de la largeur des bandes et de la distance à laquelle le poisson faisait la distinction. Acuité visuelle maximale de l'albacore: 0,274; à titre de comparaison, le chiffre est de 0,180 pour la bonite à ventre rayé (Katsuwonus pelamis) et de 0,135 pour la thonine (Euthynnus affinis). Angles visuels minimaux correspondants: 3,65, 5,56, et 7,41 minutes.

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AGUDEZ VISUAL DEL ATUN, Thunnus albacaresExtracto

Se amaestró al atún amarillo, Thunnus albacares, a que reaccionara de manera distinta ante imágenes de tiras verticales y horizontales. La luminancia de la imagen se redujo hasta que el atún no pudo distinguir entre las tiras. La agudeza visual se calculó a partir de la anchura de las tiras y la distancia desde la cual el pez las podía distinguir. La máxima agudeza visual de T. albacares es de 0,274, contra 0,180 en el caso del barrilete, Katsuwonus pelamis, y 0,135 para el pequeño atún, Euthynnus affinis. Los ángulos visuales máximos correspondientes son de 3,65, 5,56 y 7,41 minutos.

1 INTRODUCTION

Riggs (1965) classified the tasks required of subjects in various tests to measure visual acuity as: detection, recognition, resolution, and localization. Detection is the perception of the presence of an object, recognition is the identification of an object, resolution is the perception of the separate elements of a pattern, and localization is the perception of the displacement of a part of an object. The type of visual acuity with which this paper is concerned is resolution.

Previous experimental measurements of the visual acuity of fishes have been reported by Brunner (1934) for the European freshwater minnow, Phoxinus laevis; by Yamanouchi (1956) for the marine convictfish, Microcanthus strigatus; by Baerends, Bennema, and Vogelzang (1960) for the cichlid, Aequidens portalegrensis; and by Nakamura (in press) for the skipjack tuna, Katsuwonus pelamis, and the little tunny, Euthynnus affinis.

On the basis of experimental measurements presented in this paper, the maximum visual acuity of the yellowfin tuna, Thunnus albacares, is greater than that of skipjack tuna and little tunny.

2 METHOD

The method required a series of trials in which the intensity of the stimulus (an image consisting of black and white stripes of equal width) was successively reduced until the threshold was reached. A fish was required to distinguish between vertically and horizontally striped images from a given distance, when the images were back-projected on a plate of opal glass which rested against a window of the experimental tank. The fish was trained to swim down the tank to a food-drop area, where it was rewarded with food, when vertical stripes were projected. When horizontal stripes were projected, the fish was trained to turn before it reached the food-drop area; if it failed to turn and return to the other end of the tank, it received an electrical shock. The luminance (also called photometric brightness--luminous intensity per unit area in a given direction) of the striped image was reduced in successive trials until the fish was no longer able to discriminate vertical from horizontal stripes. One fish was used during each experiment. Each fish was adapted to an illumination of 170 luxes.

Visual angle was computed from the width of the stripes and the distance from the fish's eyes to the image. Visual angles were varied during the experiments by changing the width of the stripes and the distance between the fish and window at the instant the projector was turned off. Visual acuity was calculated as the reciprocal of the visual angle.

The diminution in luminance of the white stripes with distance was determined by measuring the volume attenuation coefficient, α . Photographs of the striped image were taken underwater at various distances, the film was examined densitometrically, and the luminance of the white stripes was plotted against distance. α , an index of water clarity, was equal to the slope of the plotted line. α was used to calculate the attenuated luminance of the white stripes at the fish's eyes.

The experimental tank was enclosed in a Quonset hut. Experiments were conducted from an observation booth so that the observer could not be seen by the fish. Remote controls were used to operate the projector and electrical shocker. Food was dropped from a feeding tube attached to the booth.

Detailed descriptions of the training and experimental procedures, the apparatus and the experimental tank, and the calculations of visual acuity and luminance have been given by Nakamura (1968).

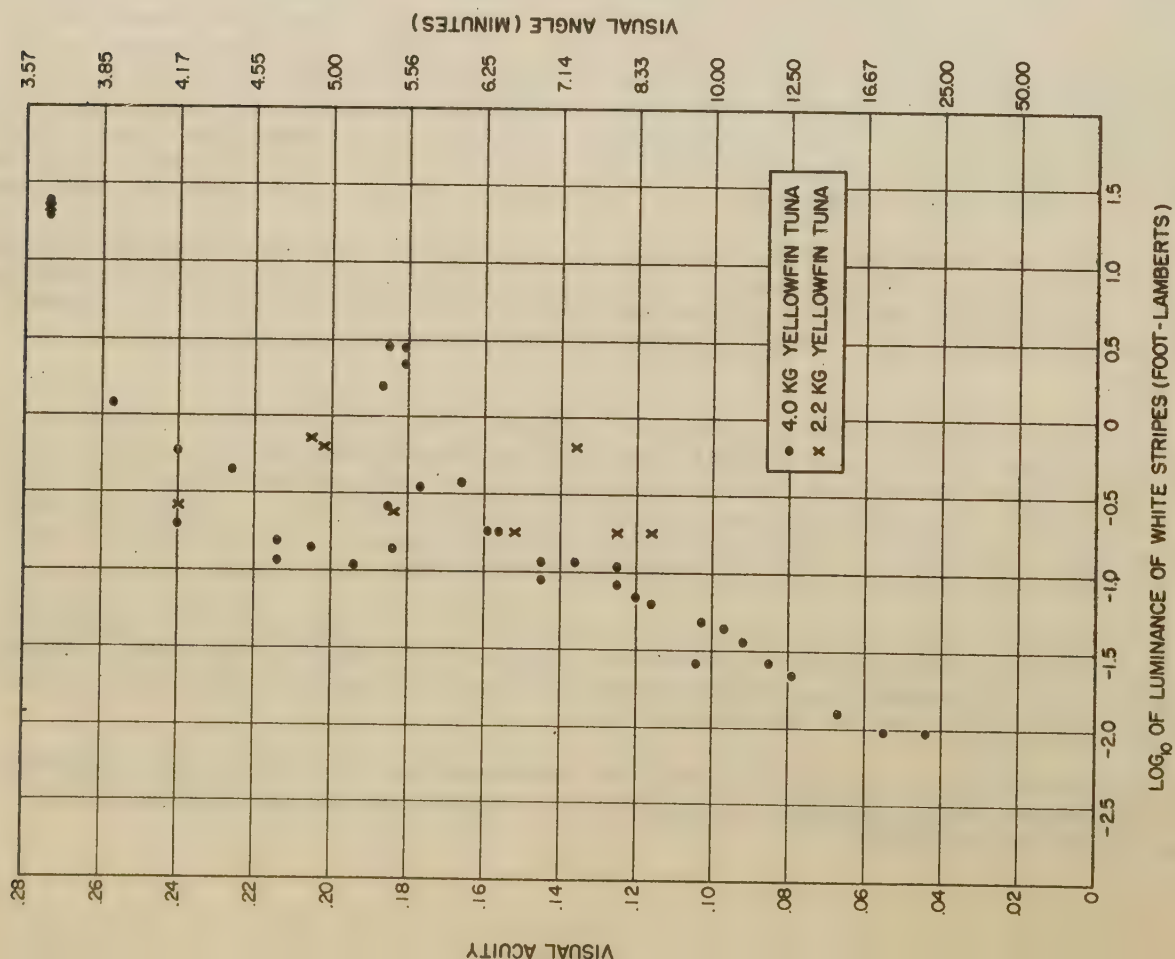


Fig. 1 Visual acuity of yellowfin tuna (*Thunnus albacares*)

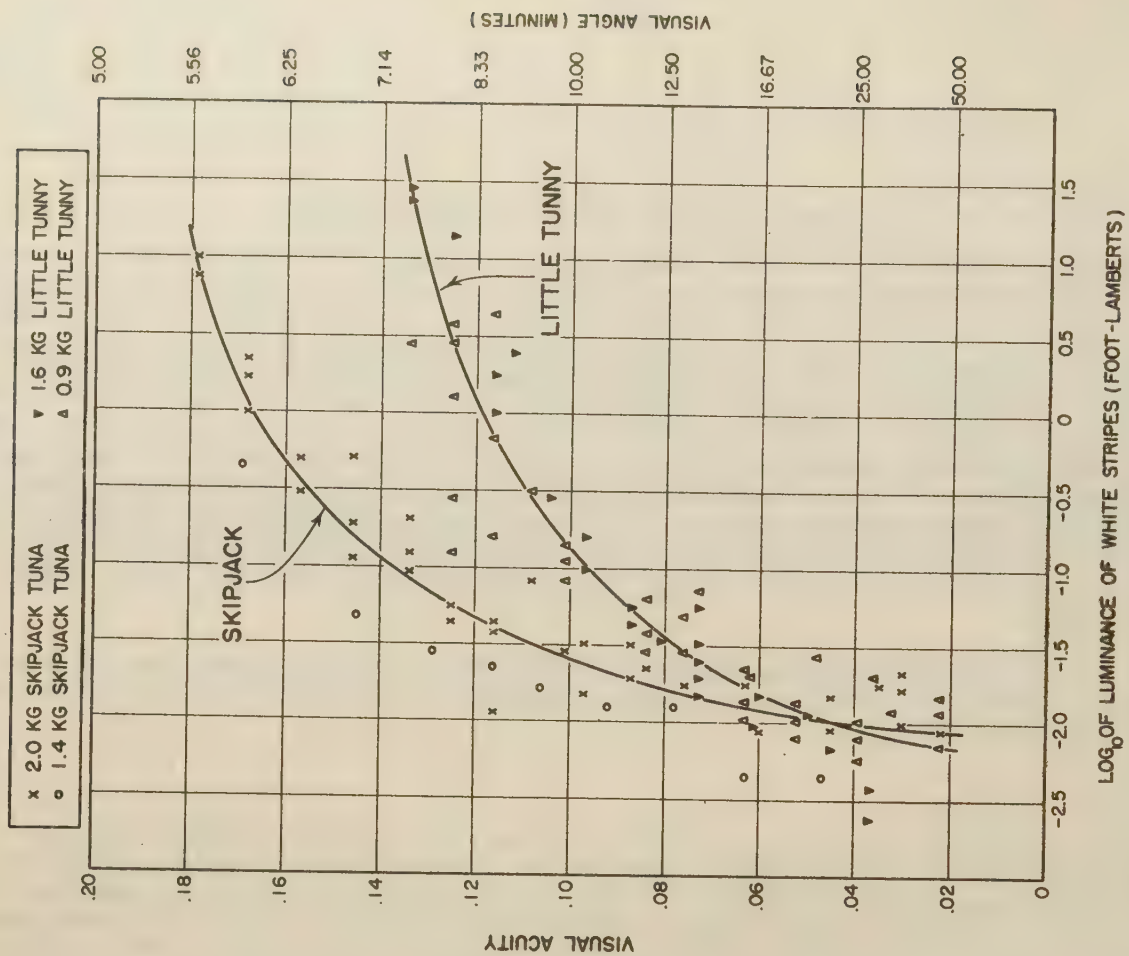


Fig. 2 Visual acuity of skipjack tuna (*Katsuwonus pelamis*) and little tunny (*Euthynnus affinis*). Curves fitted by eye. (from Nakamura, in press)

3 VISUAL ACUITY OF YELLOWFIN TUNA

Two yellowfin tuna were tested; their weights were about 2.2 and 4.0 kg and fork lengths about 49 and 59 cm.

Results of the measurements of visual acuity are presented in Fig. 1. Visual acuity increased as the luminance of the image increased. The maximum visual acuity was 0.274.

The visual acuity of yellowfin tuna was greater than that of skipjack tuna and little tunny at intermediate and high luminances, and similar to that of the other two species at low luminances (Fig. 2). At intermediate luminances, the variability of the data increased with the greater visual acuities of the three species. Little tunny had the lowest visual acuity and the least variability; skipjack tuna had an intermediate visual acuity and variability; and yellowfin tuna had the highest visual acuity and the greatest variability. At high luminances, the maximum visual acuity for yellowfin tuna (0.274) was greater than that for skipjack tuna (0.180) and little tunny (0.135). The minimum visual angles for the three species were 3.65, 5.56, and 7.41 minutes, respectively.

4 MAXIMUM DISTANCES OF RESOLUTION

Maximum distance of resolution of an object can be calculated by reversing the calculations for visual acuity. The inverse of visual acuity equals visual angle. Bisection of the visual angle yields a right triangle. The tangent of one half of the visual angle in minutes of arc equals one half of the width of the object divided by the distance.

These calculations would pertain to fish in waters with clarity and illumination similar to those in the experimental tank. For example, such conditions would be found at a depth of 36 m with an unobscured sun at an altitude of 65 degrees and with an alpha of 0.18 natural log per meter. Also, the brightness of the viewed object would be assumed to contrast sufficiently with the background for visual detection.

Under these conditions, the maximum distances of resolution of the vertical bars and stripes which occur during feeding on the flanks of skipjack tuna, little tunny, and yellowfin tuna can be calculated. The vertical bars on skipjack tuna and little tunny about 40 cm long are about 2 cm wide. These bars would be resolvable at maximum distances of 12.4 m by skipjack tuna and 9.3 m by little tunny (Nakamura, in press). On yellowfin tuna about 50 cm long, lightly colored vertical stripes about 0.5 cm wide occur on the dorsolateral surfaces. Although the yellowfin tuna has a greater visual acuity than the other two species, it can resolve these feeding stripes on a companion at a maximum distance of only 4.7 m.

Maximum distances of resolution can be calculated for fishing gear also. For example, a hook 3 mm in diameter would be resolvable at a maximum distance of 2.8 m by a yellowfin tuna, 1.9 m by a skipjack tuna, and 1.4 m by a little tunny. Twine 1 mm in diameter would be resolvable at a maximum distance of 0.9 m by yellowfin tuna, 0.6 m by skipjack tuna, and 0.5 m by little tunny.

The time in which a fish must decide whether or not to continue its course of action can be calculated from these resolution distances and swimming speeds. While feeding, a yellowfin tuna about 52 cm long swims between 1.6 and 5.5 m per second, a skipjack tuna about 48 cm long between 0.3 and 6.9 m per second (Yuen, 1966), and a little tunny about 40 cm long between 3.8 and 10.0 body lengths per second (Walters, 1966). At these speeds and with the resolution distances given in the above paragraph, the times during which a fish must decide whether or not to take a hook 3 mm

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in diameter are between 0.35 and 1.19 seconds for yellowfin tuna, 0.28 and 6.33 seconds for skipjack tuna, and 0.48 and 1.25 seconds for little tunny. The times during which a fish could evade twine 1 mm in diameter are between 0.09 and 0.31 second for yellowfin tuna, 0.07 and 1.67 seconds for skipjack tuna, and 0.12 and 0.33 seconds for little tunny.

Distances of resolution of an object can be minimized by reducing the contrast of the brightness of the object with the brightness of the background. For example, a silvery hook could be rendered less conspicuous by painting it black. Hester and Taylor (1965) have found dark objects less conspicuous than light objects in the sea. Also, use of clear synthetic fibers such as nylon in nets reduces the contrast between the webbing and the background. Conversely, distances of resolution can be increased by using bright objects. For example, baitfish on longlines would be resolvable at greater distances if the baitfish were silvery rather than dark. Since the baitfish is dead, it would not be in a normal swimming position. Thus the reflecting platelets (Denton and Nicol, 1966) would not be normally oriented. This effect would increase the contrast between the brightness of the baitfish and the brightness of the background.

5 REFERENCES

- Baerends, G.P., B.E. Bennema and A.A. Vogelzang, Über die Änderung der Sehschärfe mit dem Wachstum bei Aequidens portalegrensis (Hensel) (Pisces, Cichlidae). Zool.Jb.(Syst.), 88(1):67-78
- Brunner, G., Über die Sehschärfe der Elritze (Phoxinus laevis) bei verschiedenen Helligkeiten. Z.vergl.Physiol., 21(2):296-316
- Denton, E.J. and J.A.C. Nicol, A survey of reflectivity in silvery teleosts. 1966 J.mar.biol.Ass.U.K., 46:685-722
- Hester, F. and J.H. Taylor, How tuna see a net. Comml Fish.Rev., 27(3):11-6
1965
- Nakamura, E.L., Visual acuity of two tunas, Katsuwonus pelamis and Euthynnus affinis. 1968 Copeia, 1968(1):41-9
- Riggs, L.A., Visual acuity. In Vision and visual perception, edited by C.H. Graham, 1965 New York, John Wiley and Sons, Inc., pp. 321-49
- Walters, V., On the dynamics of filter-feeding by the wavyback skipjack (Euthynnus affinis). 1966 Bull.mar.Sci.Gulf Caribb., 16(2):209-21
- Yamanouchi, T., The visual acuity of the coral fish Microcanthus strigatus (Cuvier and Valenciennes). 1956 Publ.Seto mar.biol.Lab., 5(2):133-56
- Yuen, H.S.H., Swimming speeds of yellowfin and skipjack tuna. Trans.Am.Fish.Soc., 1966 95(2):203-9

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THE BEHAVIOUR OF Sardinella aurita VAL.,
IN RELATION TO LIGHT AND TEMPERATURE

by

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Abstract

Observations were carried out in the Gulf of Guinea to ascertain whether Sardinella aurita Val. could be attracted by light during the period of hydrographic stability, when a distinct thermocline prevents this fish from penetrating into the uppermost layer. The experimental light fishing which has been carried out off Ghana under the Technical Assistance of the FAO since 1963 may be considered as the first successful trial of this kind in the Gulf of Guinea. Because the sardinella season off Ghana (particularly canoe fishing) is confined at present to the short upwelling season from July to October, the possibility of extension of the fishing season by means of light attraction assumes considerable importance.

COMPOTEMENT DE Sardinella aurita VAL. EN
FONCTION DE LA LUMIERE ET DE LA TEMPERATURE

Résumé

Des observations ont été effectuées dans le golfe de Guinée pour déterminer si Sardinella Aurita Val. pouvait être attiré par la lumière en condition de stabilité hydrographique, lorsqu'une nette thermocline l'empêche d'accéder à la couche la plus supérieure. On peut considérer que la pêche expérimentale au feu effectuée depuis 1963 au large du Ghana avec l'assistance technique de la FAO constitue le premier essai de ce type couronné de succès dans le golfe de Guinée. La campagne ghanéenne de la sardinelle (notamment la pêche pratiquée à partir de pirogues) étant actuellement limitée à la brève période des "upwellings" (juillet-octobre), la possibilité d'accroître la durée de la campagne de pêche grâce à l'attraction par la lumière artificielle revêt une importance considérable.

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EL COMPORTAMIENTO DE Sardinella aurita VAL.,
CON RESPECTO A LA LUZ Y LA TEMPERATURA

Extracto

En el Golfo de Guinea se realizaron observaciones para determinar si Sardinella aurita Val. podría ser atraída por la luz durante la estabilidad hidrográfica, en la que una termoclina perfectamente diferenciada impide que estos peces penetren en la capa superior. Los experimentos de pesca con luces que desde 1963 se realizan en aguas de Ghana con asistencia técnica de la FAO, pueden considerarse como el primer ensayo de esta clase que haya tenido éxito en el Golfo de Guinea. Como la campaña de sardinella en aguas de Ghana (particularmente la que se pesca desde canoas) se limita en la actualidad a la corta estación de aguas de afloramiento de julio a octubre, la posibilidad de prolongar la campaña de pesca mediante la atracción con luces adquiere enorme importancia.

1 RELATION BETWEEN CATCH AND SEAWATER TEMPERATURE

It is evident from available fisheries statistics that sardinella catches by canoes (gillnets) and by purse seiners (purse seines without light attraction equipment) in the upwelling off Ghana and Ivory Coast (July to October and August to September, respectively) are negatively correlated with the temperature of the upper layer of the sea. Off Ghana a surface temperature below 25°C seems generally to coincide with the canoe fishing season for Sardinella aurita, while a temperature below 23°C might be related to the best catches. Close correlation between sardine catch and temperature of the upper sea layer has been observed in Ghana (FAO/UN, 1965 and Zei, 1966) and in the Congo (Pointe Noire) (Troadec, 1964). In Fig. 1 and 2 the canoes' and purse seiners' fortnightly and monthly catches respectively are plotted against yearly sea surface temperature.

While the daily temperature curves in Fig. 1 represent temperature from one location only, namely the Tema fishing harbour, the sardinella catches are reported from the whole coast, from Keta in the east to Axim in the west. However, the patterns of upwelling off Tema as seen from the yearly temperature curves, might easily be taken as typical patterns for most of the Ghanaian sardine waters. This could be confirmed by the monthly hydrographic transects which have been regularly carried out by the Fishery Research Service in Ghana since 1962 (FAO/UN, 1965). From 1962 to 1966 four different courses of upwelling were recorded: strong but normal in extent in 1962; short and feeble upwelling in 1963; strong and extensive in 1964; and rather irregular, short and feeble in 1965 and 1966. The seasonal catch of sardinella by canoes varied accordingly, yielding the highest catches in 1964 and lesser catches in 1963, 1965 and 1966. It must be remembered that in 1963 and 1965 because of feeble upwelling sardinella did not approach the coast sufficiently and were consequently available only for long range motorized canoes.

As the canoe fishing for sardinella by gillnets depends entirely on the appearance and availability of shoals in the surface layer it is obvious that the correlation between the catch and surface temperature has to be interpreted as a restricted tolerance of Sardinella aurita to high temperature. As the sailing range of canoes is mainly confined to the shallower part of the shelf it is evident that there will be little fishing when upwelling is weak and does not come within reach of the canoes (compare the relationship of catch to temperature for 1963 and 1965). This also applies to the minor upwelling season which occurs between January and March, when the surface temperatures decline to about 25°C.

The catches of purse seiners (without lights) are, however, less dependent on the appearance of sardinella shoals on or near the surface, or on the upwelling, since sardinella below the surface could be detected and caught as soon as they assembled in catchable numbers. It is the grouping of sardinella in shoals and the successful searching for them that make purse seining during the upwelling period easier and more successful than during the period of hydrographic (thermic) stability. Troadec (1964), studying the catch statistics of two purse seiners fishing in 1962 and 1963 in the coastal waters off Pointe Noire, Congo, found that vulnerability to the purse seines (expressed as an index of variation) changed from 1 to 4 according to change of warm season to cold (his index of variation applies to temperature at the 20 m isobath). From the graphs presented in Fig. 2 one might conclude that the vulnerability ratio is even more conspicuous and extreme, in spite of the minor upwelling period which is reflected in the catches during January to March.

2 LIGHT FISHING EXPERIMENTS

In order to try to extend the sardinella season in Ghana beyond the upwelling period (especially for canoe fishing) some experimental light fishing was initiated under FAO Technical Assistance, with promising results (FAO/UN, 1965). These experiments also

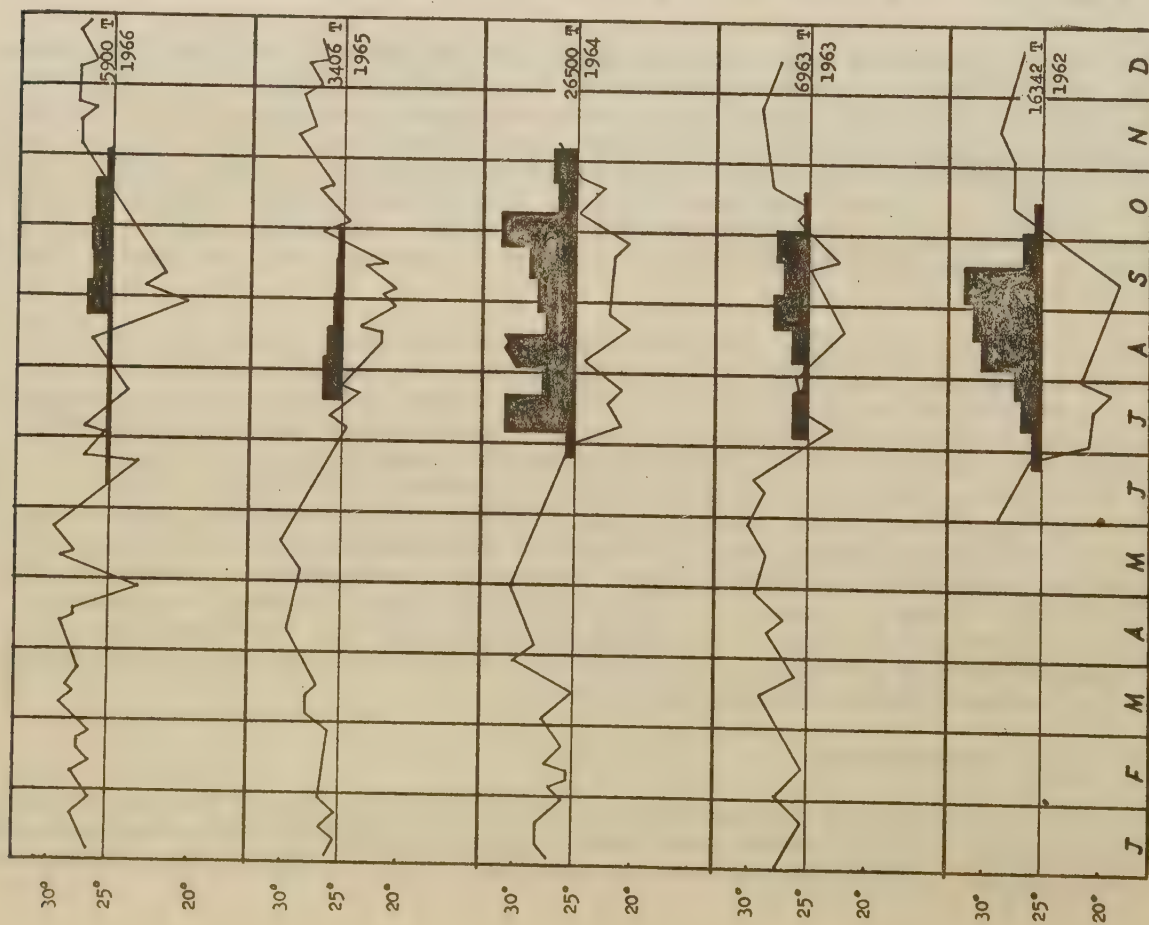


Fig. 1 Catches of *Sardinella aurita* by canoes in relation to sea surface temperatures. (Landings along the shore of Ghana).

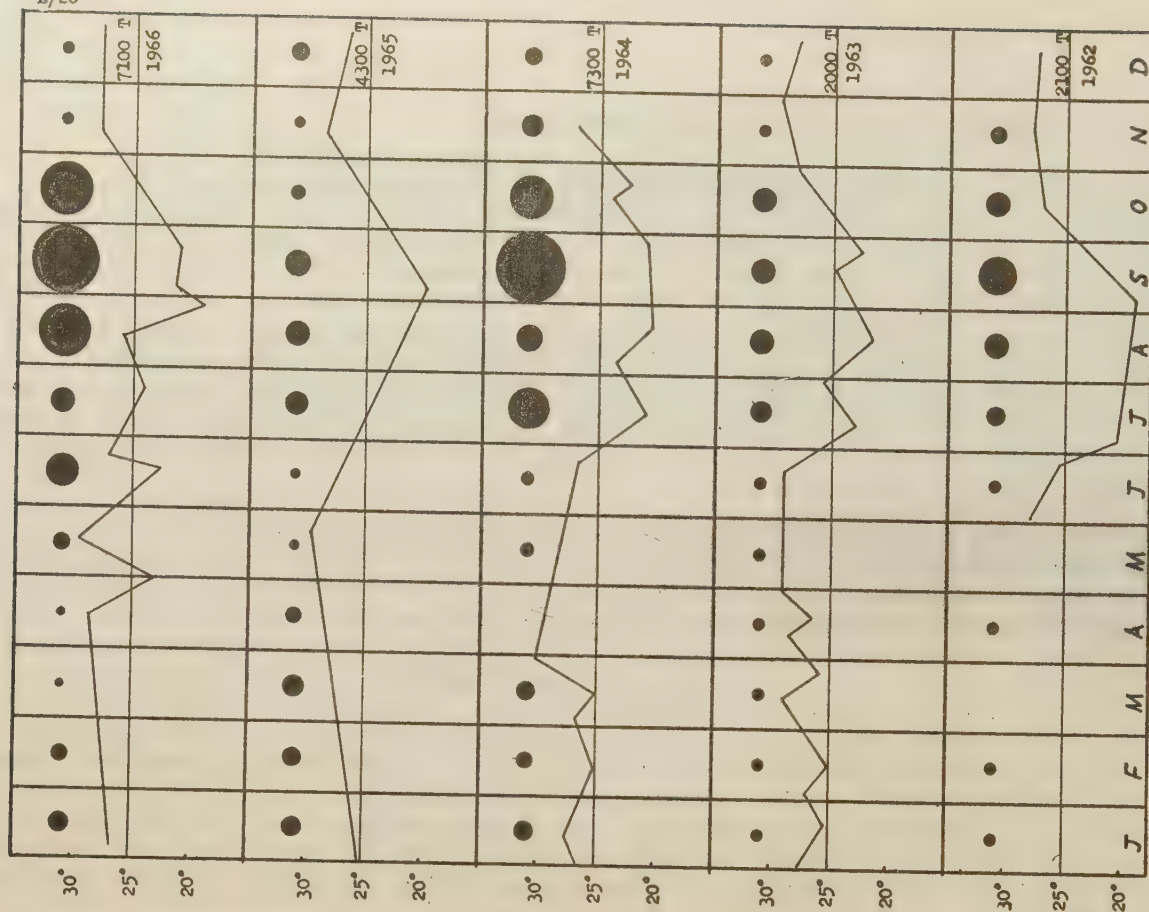


Fig. 2 Catches of *Sardinella aurita* by purse seiners in relation to sea surface temperatures. (Tema landings).

confirmed the close correlation between the vertical distribution and concentration of Sardinella aurita by artificial light and the vertical distribution of the temperature.

The light fishing experiments were carried out mainly from January to June, i.e. during the minor upwelling and during the period preceding the major upwelling. Only a few experiments were performed during July/August when the thermocline had been broken down and the surface temperature dropped below 23°C. The underwater lamps, consisting of 1 or 2 bulbs of 500 W each, were switched on over depths ranging from 35 to 100 m, at about 4 to 9 mi offshore. The lighting was carried out at different moon phases. While during the dark nights 8 light attractions out of 10 were successful, no fish could be attracted at full moon, and only a negligible amount of fish was gathered below the light at half moon.

The behaviour of sardinella in artificial light showed a more or less constant pattern. After approximately 15 to 45 min the first traces of fish appeared on echograms. When the fish did not appear during the first hour of lighting no further attracting was successful. During the first quarter of an hour of attracting and gathering, sardinella were rather sensitive to any sudden noise in the boat; usually there was an immediate shock reaction during which the fish sank or disappeared but soon after rose and concentrated again. After a rather short period of time (in comparison to the Mediterranean sardine) sardinella became accustomed to light so that any disturbance, such as the weighing of anchor, starting the engine, or casting the bathythermograph, did not disturb them much. During the period of hydrographic stability, when there was a sharp thermocline, the fish seldom rose into the layer above the thermocline, usually gathering in deeper layers below it. It is evident from the echogram/bathythermogram for 12 April 1967, that the bulk of fish remained below the upper layers of the thermocline 0.2°/m at 26 to 28°C and did not penetrate through them (Fig. 4). During the minor upwelling (January to March) sardinella gathered below the light and sometimes penetrated through the thin and indistinct thermocline (small temperature gradient 0.1°/m at 23 to 25°C up to the surface (Fig. 3), when the surface temperature dropped below 25°C. The minor upwelling period off Ghana is characterized by a rather strong oscillation of surface temperature between 24 and 26°C, while the thermocline, if any, is very feeble. During the major upwelling, when the temperature drops below 25°C, even down to 18°C, shoals of sardinella appear in the uppermost layer and are visible on the surface in smaller or larger patches by day or by night (bioluminescence). Therefore any positive phototaxis might be misinterpreted. Moreover during the major upwelling the waters are very turbid, the Secchi disc only being visible at 5 to 6 m. The turbidity is another factor which causes diffusion of the light, which then has little or no effect on the fish.

The fishes attracted by light were for the most part Sardinella aurita, occasionally mixed with S. eba, Anchoviella guineensis, Decapterus spp., Brachydeuterus auritus, bellonids, some small sharks, flying fish etc. At 40 to 70 m depth fish sometimes form a thick layer on the bottom up to the thermocline. When the light is switched off sardinella usually rise and eventually disappear.

The quantity of sardinella attracted by artificial light varied considerably with weather, moon phases, depth and position at sea. On the average, sardinella formed a layer about 20 m thick below the thermocline while Decapterus were near the surface in dense shoals of lesser size. From observations based on occasional purse seining, echograms and air bubbles produced by rising sardinella, the quantity of fish gathered per lighting might be estimated at 10 to 30 t at least. The first trial fishing of sardinella, using lights, produced 3 to 5 t per haul.

Similar exploratory light fishing in West African waters was carried out by U.S.S.R. vessels during the first months of 1964. Most of the work was done in shallow areas of Conakry-Freetown and Abidjan-Tema. The catches primarily consisted of Sardinella aurita in rather large quantities. Currently some Japanese tuna vessels fish for

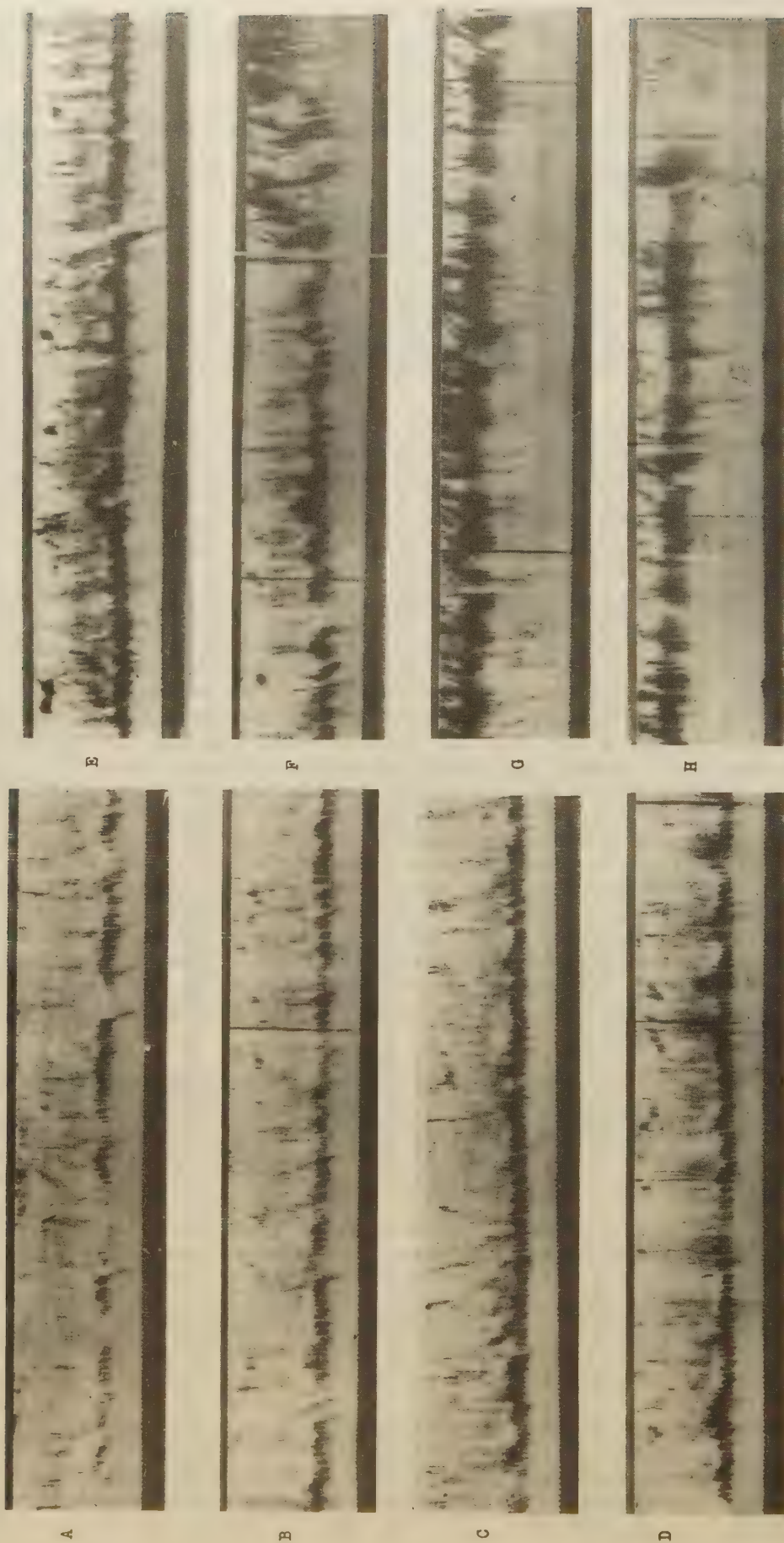


Fig. 3 Light fishing off Tema on 21/22 January 1964 from 20:30 to 05:00 h. Depth: 30 fath.

sardinella, using light, off Ghana and Ivory Coast, to serve as live bait for tuna fishing. In 1967, an Italian purse seiner started catching sardinella in Ghanaian waters using lights during the pre-upwelling season with good results.

These are the first successful trials of commercial light fishing for sardinella in the Gulf of Guinea. Once this method is widespread in this area one might expect an increase in the yearly sardinella catch, from 20 000 to 100 000 t, in Ghana and consequently an increase of up to half to one million tons for the whole of Gulf of Guinea. The short sardinella fishing season will thus be overcome and extended over the whole year. New light attraction methods for canoe fishing would probably be advantageous. The fish canning industry in the Gulf of Guinea, which at present suffers because of irregular catches, would certainly benefit if regular supply of fish could be ensured by fishing with light attraction methods.

3 REFERENCES

- FAO/UN, Report to the Government of Ghana on biological investigation of fisheries
1965 resources, based on the work of Miroslav Zei, FAO/EPTA marine fisheries
biologist. Rep.FAO/EPTA, (2001):34 p.
- Troadec, J.P., Prises par unité d'effort des sardiniers pontenegrins. Variations
1964 saisonieres de l'abondance des sardinelles dans les eaux congolaises.
Pointe Noire, ORSTOM (mimeo)
- Zei, M., Some facts on Sardinella aurita Val. in relation to temperature. Ghana J.Sci.
1966 5(3/4)

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FISH BEHAVIOUR IN RELATION TO VARIATION
IN OSMOTIC PRESSURES

by

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Abstract

Investigations were carried out on the changes in the osmotic pressure of sera in some freshwater and marine fishes under the influence of various salinities.

COMPORTEMENT DU POISSON SOUMIS A DES VARIATIONS
DE LA PRESSION OSMOTIQUE

Résumé

La communication rend compte d'études sur les modifications de la pression osmotique du sérum sanguin chez certains poissons d'eau douce et de mer sous l'influence de divers taux de salinité.

COMPORTAMIENTO DE LOS PECES CON RELACION
A LAS PRESIONES OSMOTICAS

Extracto

Se analizaron investigaciones sobre los cambios en la presión osmótica de los sueros de algunos peces de agua dulce y marinos por efecto de distintas salinidades.

The osmotic pressure of serum of freshwater carp increased from 157 meq/l up to 180 meq/l, when the fish were put into water of one per cent salinity. But, when all scales of the left side of the carp were removed in diluted M.S. 222 solution and the fish put in the saline medium, the pressures of those fish sera increased more to about 200 meq/l.

Next we observed that in the fresh water the osmotic pressures of the carp with scales removed, rapidly decreased below 120 meq/l on the first day; however, the low pressure gradually returned to normal after a week. These phenomena are caused by the effect of osmoregulatory mechanism in fish. Especially, in freshwater fish the mechanism affects strongly the permeation of water.

We have also carried out similar experiments on marine fish: when we transferred Sebastes inermis of 220 meq/l serum and Parapristipoma trilineatum of 235 meq/l serum, into one half diluted seawater, the osmotic pressure decreased to 170 meq/l and 175 meq/l respectively and such conditions were continuous for eight days, contrary to those in the case of the carp. Five species of marine fishes, Mylio macrocephalus, Sebastes inermis, Parapristipoma trilineatum, Ditrema temminoki and Fugu niphobles were put into concentrated seawater (10 grams of salt in 1 litre of seawater) and it was found that the osmotic pressure of their sera were first increased to some extent for a short time and then gradually tended to decrease to near normal level.

From these experiments, we learned that in marine fishes the osmoregulatory mechanism acts less strongly on the permeation of water into their bodies as compared with freshwater fishes, among which in similar circumstances there is a strong salt permeation into the body of the fish.

We prepared a plastic trough measuring 200 x 30 x 15 cm, divided longitudinally in two by a plate 150 cm from one end of the trough. Then in these two small troughs, we examined fish behaviour by letting in flows of seawater of two different concentrations. Ten Sebastes inermis were used for this experiment and we clearly observed that the fish showed salt selection in the two different concentrations of water. The fish which had lived in water of 11.7 per mille of chlor were reared in water of 7.82 per mille of chlor in our aquarium, and we examined their behaviour in two different concentrations such as 17.0 per mille and 7.82 per mille. In the beginning they selected the more concentrated water rather than diluted water. But we observed that during a week of adaptation, their tendencies of salt selection were altered and nine fish selected 7.82 per mille, while only one stayed in water of 9.4 per mille of chlor water. Among the fish reared in 18.5 per mille salinities in our aquarium, seven of them chose the water of 15.7 per mille and only three of them selected water of 13.8 per mille.

The results of these experiments showed that marine fish are not only sensitive to the various salt concentrations but also that their preference for media of certain salinities vary according to the acquired osmotic pressures of their bodies. After these experiments, it is believed that the course of some fish migrations can be perhaps predicted if the relation between osmotic pressures of fish sera and environmental waters is cleared up sufficiently.

In Japan Seriola quinqueradiata is caught by large dragnets. When we examined the salinity of the surrounding waters where the big fish schools were caught, we found that the fish are very sensitive to the salt concentration; the fish schools always gathered in water of about 19.0 per mille of chlor.

From the results of these studies we believe we may be able to learn not only about fish behaviour in general, but also about the relationship of Seriola migration and the character of the water masses. We intend in our programs to continue the studies of the influence of environmental factors on the osmotic pressures of sera in various species of marine fishes.

THE NATURAL LIGHT FIELD UNDERWATER

by

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Abstract

Features of the natural light environment experienced by fish are described in some detail and are related to the visual problems that these features create. The features discussed include the Snell circle which is observable from near the surface, the angular distribution of radiant energy, the penetration of diffuse as well as collimated light, the scattering of light by particulate matter, the effects of spectral absorption, and the generation and attenuation of the contrast of objects against their backgrounds. The procedure for determining the apparent contrast of objects is outlined.

LA LUMIERE SOLAIRE DANS LE MILIEU SOUS-MARIN

Résumé

L'auteur décrit en détail les caractéristiques de la lumière naturelle du milieu où vit le poisson, et les rattache aux problèmes visuels qui en découlent. Parmi les points examinés figurent le cercle de Snell, observable à proximité de la surface, la distribution angulaire de l'énergie radiante, la pénétration de la lumière par les particules en suspension, les effets de l'absorption spectrale, et la production ou l'atténuation du contraste entre les objets et l'arrière-plan. La communication expose brièvement une méthode pour déterminer le contraste apparent des objets.

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EL CAMPO DE LUZ NATURAL SUBMARINO

Extracto

Se describen con detalle las características de la luz ambiental natural que observan los peces y se relacionan con los problemas visuales que crean. Las características examinadas son el círculo Snell que se observa cerca de la superficie, la distribución angular de la energía radiante, la penetración de la luz difusa y de la colimada, la dispersión de la luz por partículas de materia, los efectos de la refracción espectral y la generación y atenuación del contraste de objetos contra sus fondos. Se esboza el procedimiento para determinar el contraste aparente de objetos.

1 SNELL'S LAW

Perhaps the best known feature of the underwater light environment is the existence of the so-called Snell Circle through which all the light that enters the water from the sun and sky must come. This circle, or "manhole" as it is sometimes called, is a manifestation of Snell's law, given in Eq. (1):

$$n \sin i = n' \sin r \quad (1)$$

where, n and n' are the indices of refraction of air and water respectively and the angles i and r are the angles of incidence and refraction measured from the perpendicular to the water surface. In order to apply this law to explain the existence of the Snell circle, we ask what happens to the ray of light that arrives at the water surface at an angle of 90° from the normal, (i.e. $i = 90^\circ$). Since $n = 1$ for air and $n' = 4/3$ for water, Eq. (1) becomes $\sin r = .75$, and the angle r would be 48.6° . In terms of visual observation this means that if an eye is located below a calm water surface and observation is toward the surface, the horizon will be seen at an angle of 48.6° from the zenith. It is perhaps obvious that as a consequence of the Snell circle, a fish swimming close to the surface can easily see a ship, or a small boat, or an angler on the shore. Perhaps not so obvious is the fact that the fish would see objects near the horizon as if they were lying horizontally on the water.

Figure 1 is a photograph of the Snell circle taken with a wide angle camera lens. An ordinary camera lens would not be able to secure a picture of the complete circle because the angular field of an ordinary camera is only about half that subtended by the Snell circle. The diameter of this circle in angular measure is very nearly 187° from the point of observation. The picture was obtained in a tank of water. The water surface was undisturbed by ripples. Note the image distortion that occurs near the edges of the circle. Note also the faucet handle which appears to be mounted horizontally but is in fact mounted vertically.

Figure 2 is a more analytical photograph from the same tank. In this figure, as before, the water surface compresses 180° of sky dome into the bright central Snell circle. The camera lens also compresses 180° field of view under water into a circle. The scale in the picture is marked sequentially in feet with the 9 ft mark deliberately located at the water surface. As can be seen, starting from the top of the scale, the numbers are in sequence down to 10. The next number is 7 which is seen to be upside down as is the number 8 which lies below it. Then comes a double image of a bar which was painted under the number 9 to distinguish it from the number 6. Below this we see again the number 8, this time right side up. The inversion of some numerals in this photograph is due to the fact that they are seen by total interval reflection from the underside of the water surface. It is perhaps worthwhile to note that the number 9 does not show at all. This means that there is a small angle (2° to 3°) above the water surface within which objects outside the water cannot be seen, even though the surface is calm. Disturbance of the water surface by wave action breaks up the Snell circle, and any images seen within it, into fragments which will move independently of each other making recognition of objects outside the water exceedingly difficult. A fish swimming close to the surface of clear water when the surface is very calm, experiences a complex visual problem. Within the Snell circle he will see objects outside the water. If another fish above him swims out of the bright area of the Snell circle and crosses the line of sight at 48.6° the second fish suddenly appears to be two fishes, one of which is upside down, a perfect reflection of himself and equally visible. Alongside or below the first fish, there may be still other fish which, because of their position, have no accompanying reflection.

In deep water or in turbid water, the Snell circle can no longer be seen and these optical phenomena disappear. Because of the nature of the ocean environment, optical effects associated with the Snell circle may have limited influence on fish behaviour in their natural habitat. On the other hand, it might be well to consider the effect of these optical phenomena on fish undergoing study or training in laboratory tanks, where clear water and a calm water surface are often the rule.

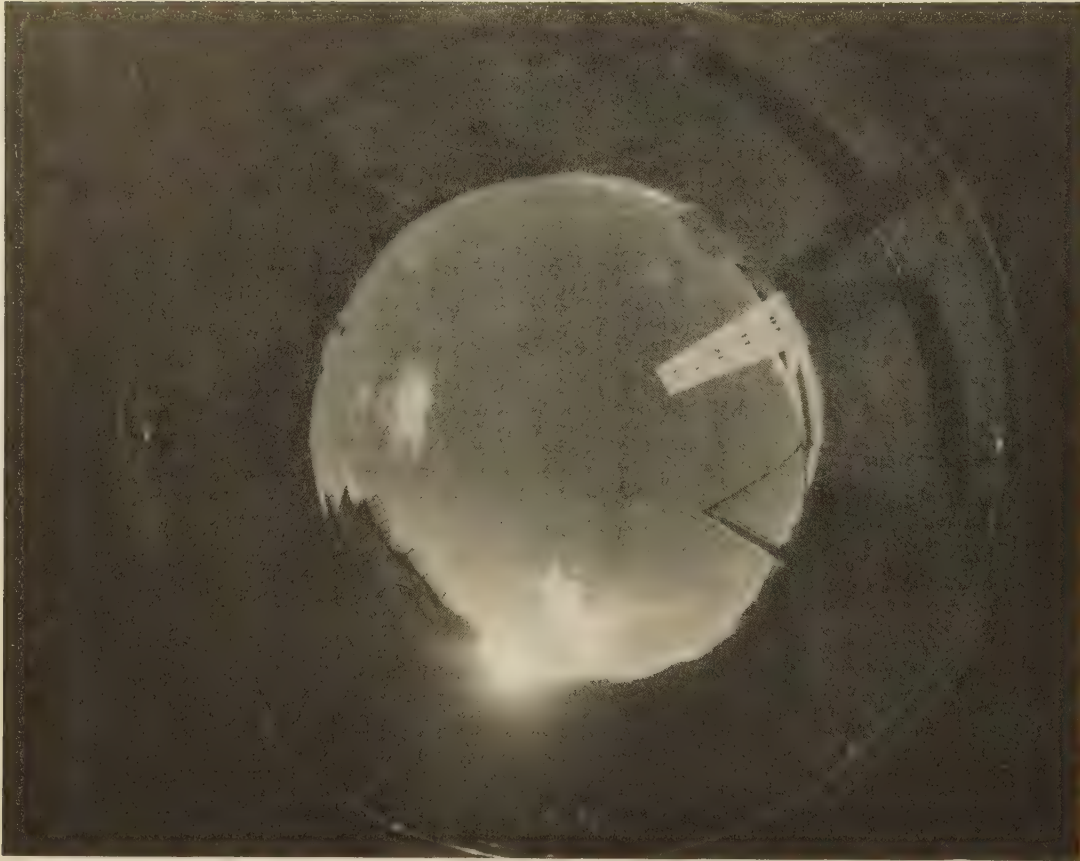


Fig. 2 The Snell circle with partly submerged scale to demonstrate total internal reflection

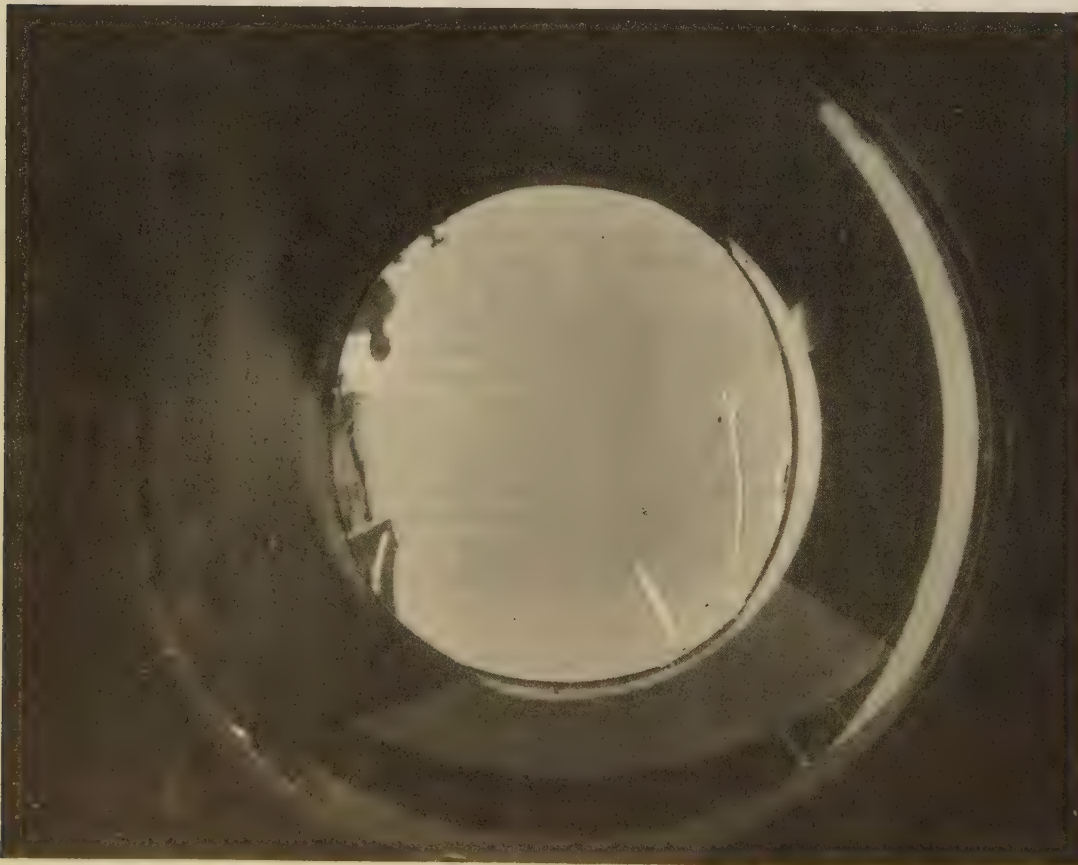


Fig. 1 The Snell circle photographed with a wide angle lens

2 UNDERWATER RADIANCE DISTRIBUTION

The relative radiance, (or brightness)^{1/} of the underwater light field in various directions has been measured for overcast sky lighting and is illustrated graphically in Fig. 3, which also illustrates the changes that take place in the distribution of radiance underwater as the depth of observation is increased. The sky lighting for Fig. 3 was uniformly overcast and remained constant for all of the curves shown. The curves themselves were all made for the same vertical plane and each represents the distribution of radiance as a function of the zenith angle from the zenith to the nadir.

Curve A shows results of observations taken in air. From $\theta = 0^\circ$ to $\theta = 74^\circ$ the curve reports the radiance of the overcast sky; at $\theta = 74^\circ$ the dark mountainous skyline is recorded, and this is followed by detail representing patches of dark rock or snow. From $\theta = 90^\circ$ to $\theta = 102^\circ$ the reflection of the mountains is recorded and this is then followed by reflection of the sky disturbed by slight wave action. At 162° the instrument's own shadow image is recorded.

Curve B shows the radiance distribution in the same direction as that in curve A but from a depth of 2.5 cm below the water surface. In the zenith direction, B shows higher radiance than A because the space light contributed by 2.5 cm of water is greater than the absorption of this same path. (It is also possible that some change took place in the zenith overcast during the short time interval between curves A and B.) Optical compression of the sky tends to keep the radiance at a high level for the first 40° . The skyline itself is very much compressed and can no longer be resolved, but the edge of the Snell circle of light appears sharp and distinct at 48° . Beyond 48° the instrument measures the radiance of the short path to the surface plus a longer reflected path that looks down into the water at an angle equal to $(180^\circ - \theta)$. This accounts for the changes in slope of the curve between 48° and 88° . Beyond 88° the path radiance is due entirely to space light from one direction only, which decreases steadily as the tilt angle increases to 180° .

Curve C shows the radiance distribution in the same direction as curves A and B but from a depth of 3.05 m. Some detail can still be observed. The steep slope between 40° and 48° is the remaining radiance change at the edge of the Snell circle of light. The dark band at 60° exhibited in B is nearly obscured by space light; in C, between 50° and 80° , it can just be seen together with its brighter rim.

Curve D shows the radiance distribution in the same direction as the other curves but from a depth of 6.1 m. At this depth all fine detail is lost, leaving only the gross changes in radiance between zenith and nadir settings.

Between 90° and 180° the underwater curves for various depths can be approximately predicted from the equation

$$N_d = N_o e^{-cd}, \quad (2)$$

where N_d is the radiance at depth D , N_o is the radiance at depth o and $c = f(\theta)$. Below 6.1 m the coefficient c tends to become independent of θ , approaching an asymptotic value which is characteristic of the hydrosol.

^{1/} The terms brightness and radiance are both commonly used to describe the radiant energy (in watts) arriving on a unit area through a unit solid angle. In this paper, brightness will be used when reference is made to a visual stimulus produced by the radiant energy thus arriving, radiance will be used when the physical response of a photodetector is implied, and also when dealing with light of a single wavelength.

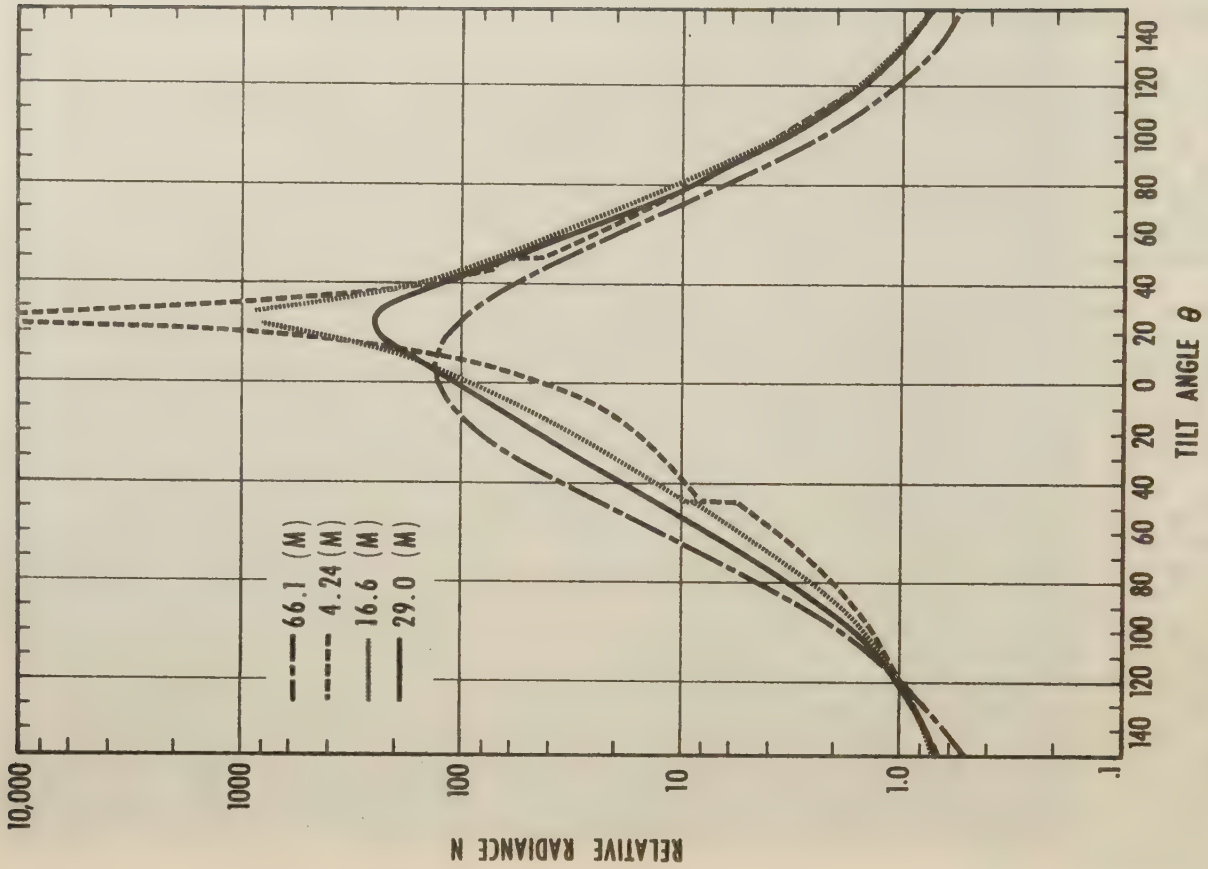


Fig. 4 Relative radiance (or brightness) in the plane of the sun as a function of tilt angle for a clear sunny day. Curves were obtained at the depths indicated and are normalized at 1200 on the side away from the sun

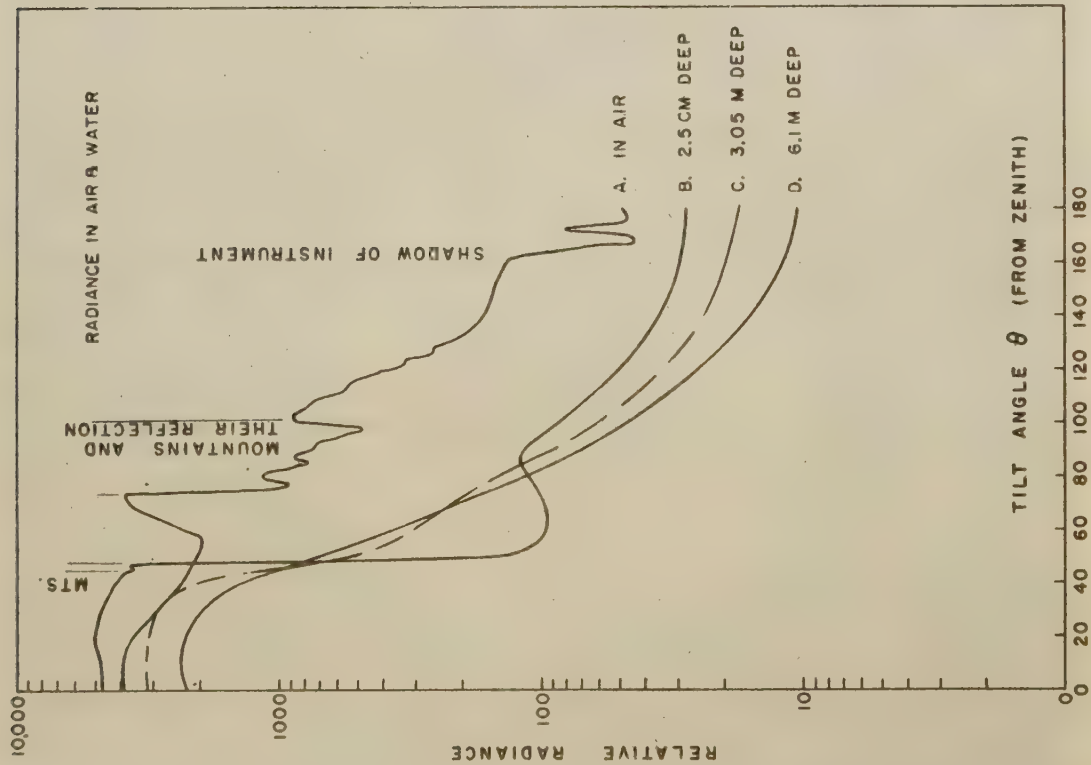


Fig. 3 Relative radiance (or brightness) as a function of tilt angle from the zenith. Curve A was obtained in air, other curves were obtained at the indicated depths in water

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Fig. 5. Relative radiance (or brightness) as a function of depth for three directions of the light field.

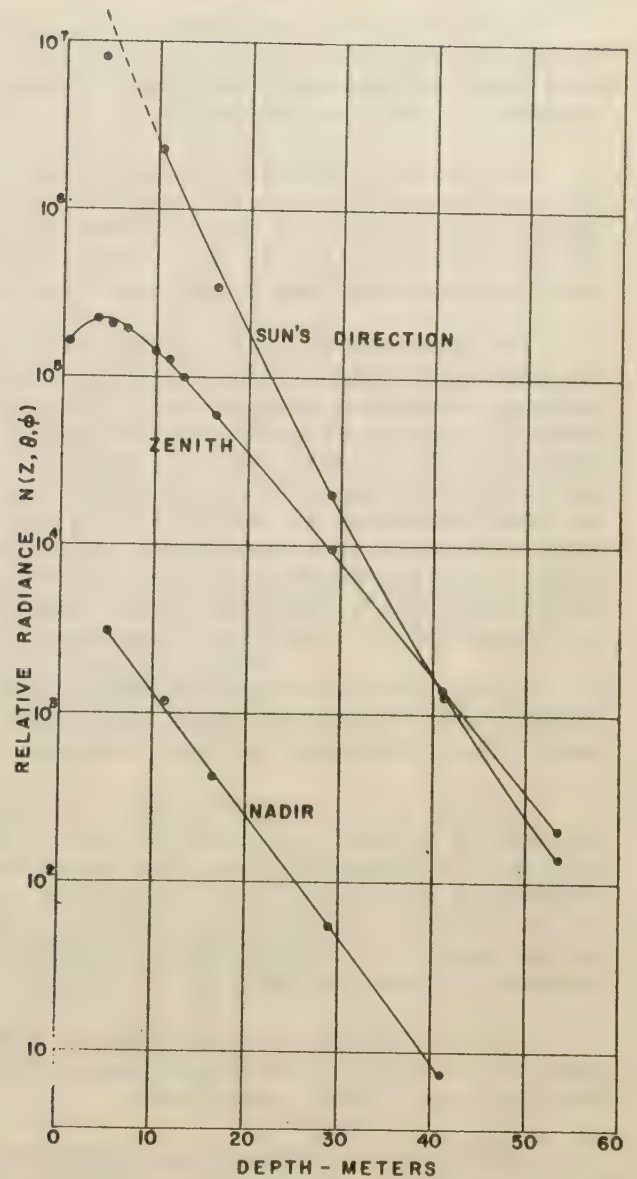


TABLE I - Location and angular subtense of glitter pattern for wind velocity of 7 m/s

Solar zenith angle	Glitter Patterns	
	Location from zenith	Angular subtense
0°	0°	nearly 20°
30°	22°	about 18°
60°	41°	about 15°
90°	probably does not exist	

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Figure 4 gives radiance data of the same kind for a clear, sunny day except that in Fig. 4 the data have all been normalized at 120° for ease of comparison. These data were taken in the vertical plane containing the sun and illustrate the distribution of radiance in the direction of the sun as well as in the direction away from the sun.

The 4.24 m curve in Fig. 4 shows the edge of the Snell circle at 48.6° and indicates the position of the sun at about 30° in the underwater field. This conforms with the actual sun altitude of about 57° at the time of the measurements. The other curves show the gradual reduction in the influence of the sun image (and Snell circle) and the change to a distribution that looks more like that for an overcast sky.

An important thing to notice about both Fig. 3 and 4 is that in some directions of the underwater light field, radiance increases with depth whereas in other directions radiance decreases with depth. This effect is detailed in Fig. 5 in which the measurement of radiance as a function of depth is shown for only three directions, the sun's direction, the zenith, and the nadir. The zenith, which appears relatively dark from just below the surface of the water, at first increases in radiance as depth increases, but then decreases in radiance at a more or less uniform rate. The sun's direction, which from near the surface has the highest radiance, is most rapidly reduced in radiance with increasing depth and at about 42 m in the figure exhibits the same radiance as the zenith and then at greater depths becomes darker than the zenith. The nadir radiance is attenuated at very nearly a constant rate, as might be expected.

In the same way the dark image of a fishing vessel, seen from below, would become lighter with increasing depth and gradually blend into the characteristic light field until from some depth the ship could no longer be detected.

In Fig. 4 the water surface was calm and the sun appeared as a bright point of light subtending an angle of about 19 min, reduced from its angular subtense in air (about 30 min) by the effect of the index of refraction of the water. If the water surface were ruffled, a glitter pattern would exist in the direction of the sun. The size and shape of the glitter pattern would depend on the wind speed and the altitude of the sun. For a wind speed of 7 m/sec, the predicted size of the glitter pattern seen from beneath the surface is given in Table I.

As depth increases, the glitter pattern subsides in radiance as illustrated in Fig. 4 and at a depth which depends upon the optical properties of the water, will no longer be a feature of the light field.

Detailed measurements have been made of the relative directional radiance in the underwater light field for a particular body of water and for both clear-sunny and overcast surface lighting. These are given in table form in Tables II, III, IV and V and are illustrated by Fig. 6 and 7.

Data of this kind will be different for different bodies of water of course, and the differences will depend on the scattering and absorbing properties of the particular water body, and also on the spectral region under consideration, since the scattering and absorbing properties of the water vary considerably with the wavelength of the radiant energy. From Tables II, III, IV and V, it can be seen that in deep water the distribution of radiant energy for a sunny sky is very much like that for the overcast sky. It can be shown in fact, that at very great depths, the spatial distribution of the sky lighting has no effect whatsoever as the spatial distribution of radiant energy underwater; that the underwater spatial distribution is influenced only by the scattering and absorbing properties of the water. Furthermore it has been predicted that in water containing scattering particles but having zero absorption, the ultimate spatial distribution of the radiant energy at great depth would be isotropic, whereas if absorption were present in water having zero scattering properties, the spatial distribution at great depth would be zero for all directions except the zenith.

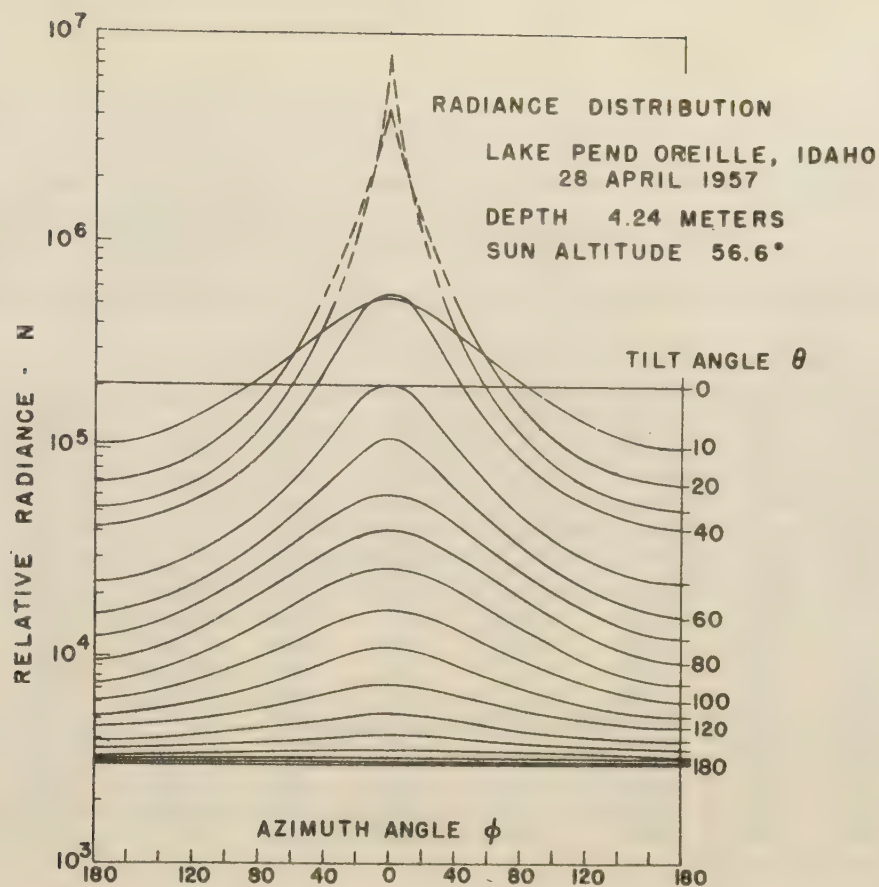


Fig. 6 Relative radiance distribution for a clear sunny day at a depth of 4.24 m

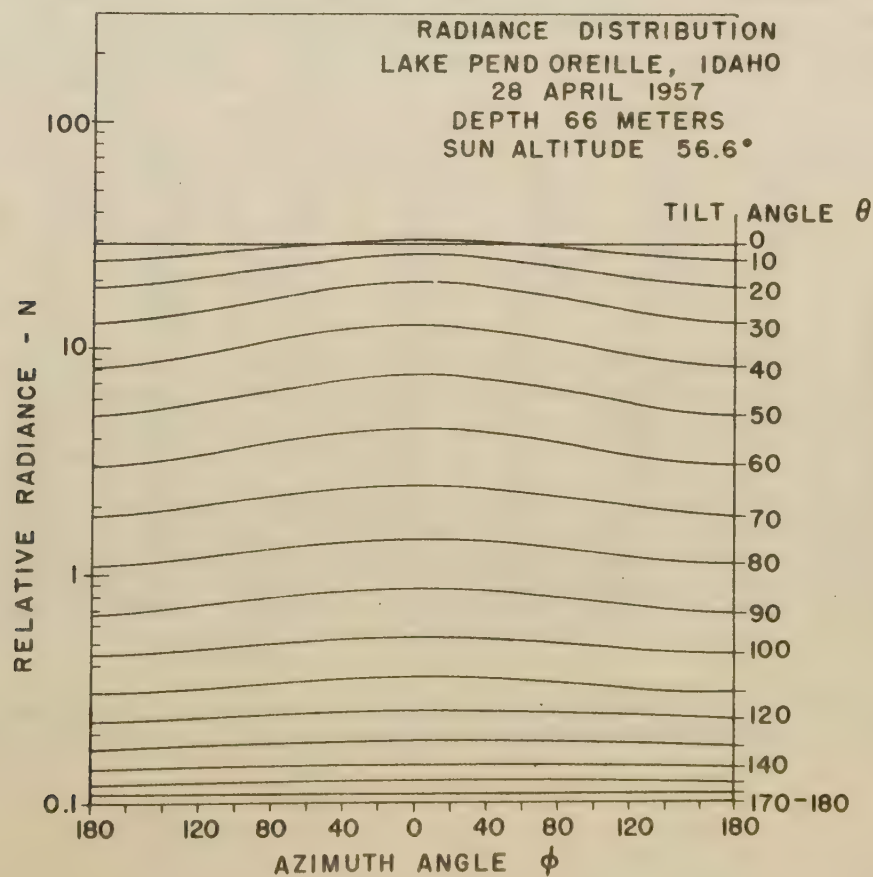


Fig. 7 Relative radiance distribution for a clear sunny day at a depth of 66 m

TABLE II - Radiance Distribution under Clear Sunny Sky
(Depth, 4.24 meters; Sun altitude, 56.6°)

[illegible]

TABLE III - Radiance Distribution under Clear Sunny Sky
(Depth, 53.7 meters; sun altitude, 56.6°)

[illegible]

Observation of the distribution of brightness underwater is ordinarily done from a fixed position, data being obtained as a function of the angle of observation. For this reason it is common practice to illustrate the data in polar coordinates. Fig. 8 is a polar plot for a single azimuth taken from Table V. The data for the lower hemisphere has been enlarged to show the shape of the distribution more clearly.

3 UNDERWATER LIGHT SCATTERING AND DISTRIBUTION

As previously stated, the changes in spatial distribution of the radiant energy underwater are brought about by the scattering and absorbing properties of the water. In describing the absorbing properties of water it is necessary to take into account the fact that diffuse light penetrates into water more easily than does a collimated beam of light. There are, therefore, a diffuse transmission and a beam transmission for water, and both will be of interest in our later discussion of contrast generation and attenuation. In measuring beam (collimated) transmission it is customary to use an artificially generated beam of collimated light and to determine the percent of this beam that passes through a fixed path length of water, (e.g. 1 m). The transmission is then obtained by means of Eq.(3)

$$T = N_r/N_0 \quad (3)$$

where, N_r is the radiance of the beam after passing through the pathlength r of water, and N_0 is the radiance of the beam introduced into the water.

A coefficient of beam attenuation can be computed from Eq. (4)

$$N_r/N_0 = e^{-\alpha r} \quad (4)$$

where, e is the base to the natural logarithms, r is the pathlength and α is the computed beam attenuation coefficient. For distilled water, the attenuation coefficient varies markedly with the wavelength of light as shown in Fig. 9 which also gives spectral attenuation coefficients for ocean and bay water (curves B and C). The beam transmission of a 10 m pathlength of distilled water can be calculated by means of Eqs. (3) and (4). For an attenuation coefficient of 1/m

$$\frac{N_r}{N_0} = e^{-10} = .000045 = .0045\%$$

For an attenuation coefficient of .5/m

$$\frac{N_r}{N_0} = e^{-5} = .0067 = .67\%$$

It can be seen that most of Fig. 9 is of little interest to problems of vision underwater. For human vision, only that portion of the curve of Fig. 9 between .4 and .7 μ on the wavelength scale need be considered. It is commonly assumed that this region is also the region of importance for fish vision.

The transmission of diffuse light is ordinarily measured by determining the ratio of the radiant energy per unit area arriving on a horizontal plane at one depth to that arriving at a lesser depth. The radiant energy arriving per unit area is called irradiance and is given the symbol H so that the irradiance transmission is simply

$$T = H_2/H_1 \quad (5)$$

where, H_2 is the measured irradiance at the greater depth and H_1 the irradiance at the lesser depth. The irradiance (or "diffuse") attenuation coefficient is computed from the equation

$$H_2/H_1 = e^{-Kz} \quad (6)$$

TABLE IV - Radiance Distribution, Overcast Sky
(Depth, 6.1 meters; sun altitude, 40.0°)

[illegible]

TABLE V - Radiance Distribution, Overcast Sky
(Depth, 42.8 meters; sun altitude, 40.0°)

[illegible]

ZENITH

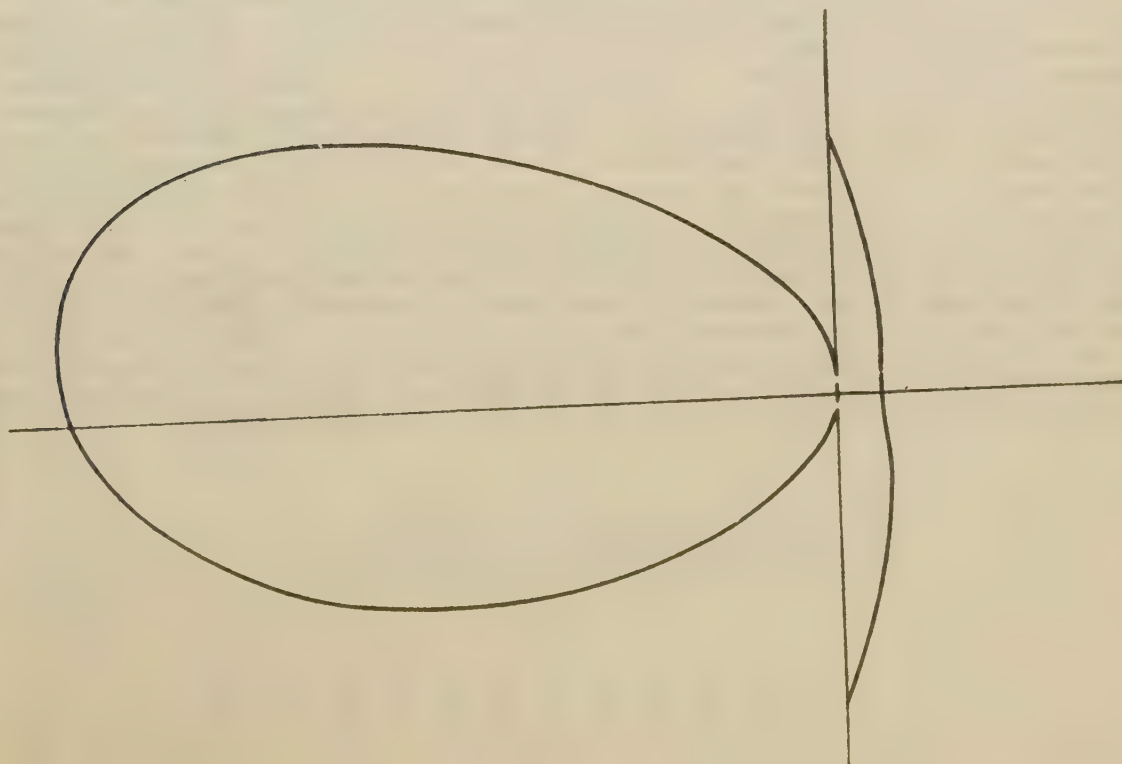


Fig. 8 Relative radiance in the plane of the sun, displayed in polar coordinates. Lower portion of curve is enlarged to exhibit its shape

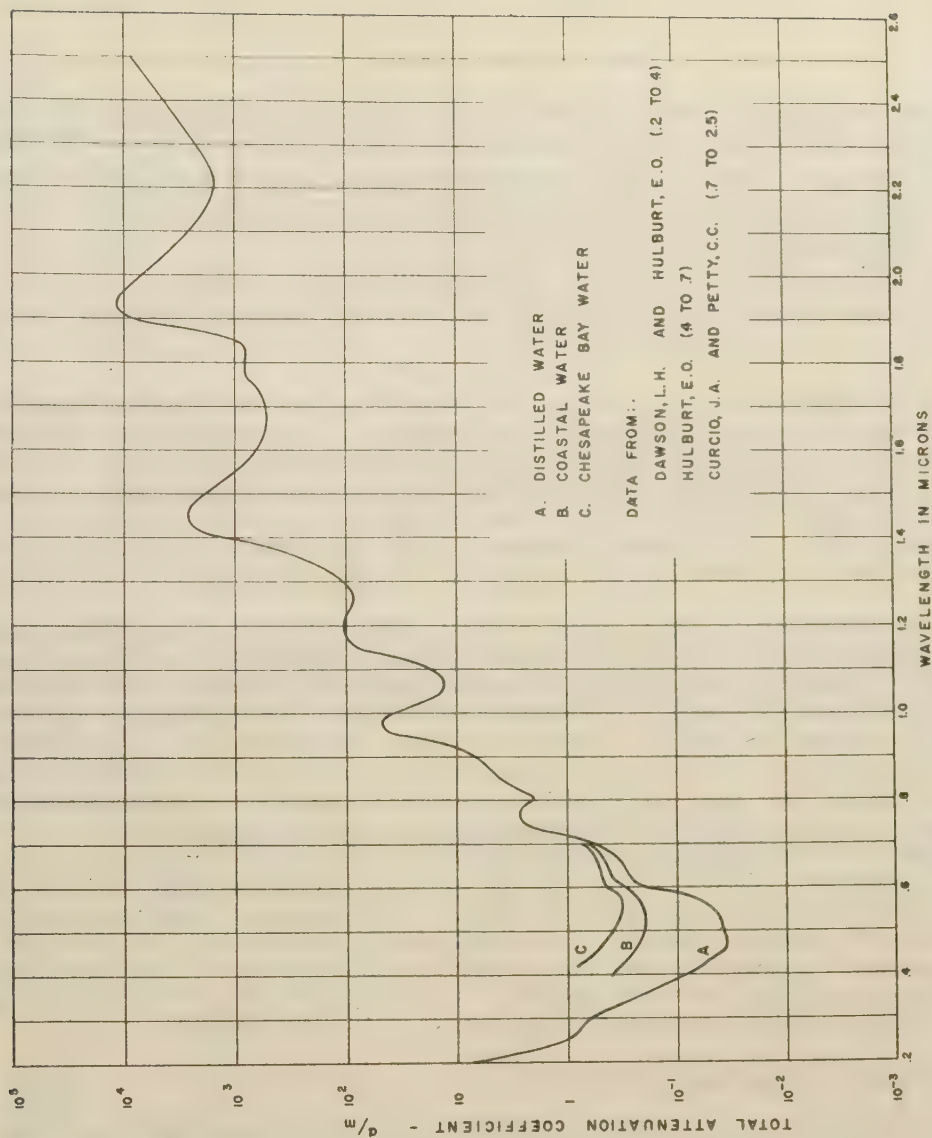


Fig. 9 The spectral variation of the total attenuation coefficient for distilled water, coastal water, and bay water

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where, K is the desired coefficient and z is the difference in depth between the two irradiance measurements. The irradiance at any depth varies markedly with the wavelength of the radiant energy. The diffuse attenuation coefficient also varies greatly with wavelength. Typical spectral values for the diffuse attenuation coefficient are given for different types of water in Tables VI and VII.

From these tables, and Eqs. (5) and (6), the transmissions of diffuse radiant flux to a horizontal surface at various depths can be calculated. Typical values are given in Table VIII.

The transmission of diffuse radiant energy to 80 m in water containing significant quantities of phytoplankton is seen to be very low indeed. Perhaps also significant is the fact that in clear, deep water the transmitted light is predominantly blue whereas in deep water containing phytoplankton, the transmitted light is predominantly green. The significance of these physical characteristics of the light field to fish that inhabit the ocean at depths of 80 to 90 m cannot be accurately appraised until more information is known about the spectral sensitivity and total visual response of the fish's eye.

Scattered light is generated in the ocean by the presence of suspended particles of various kinds and by inhomogeneities. From an optical point of view, these particles produce a kind of fog. They individually and indiscriminately scatter the light that falls on them creating a veil of space light that interferes with visibility by obscuring objects and by reducing object contrast. The scattering properties of ocean water are ordinarily studied by measuring the amount of light scattered out of a collimated beam of light. The measurements are made as a function of the angle of scattering relative to the original beam. Absolute values of the volume scattering coefficient are difficult to obtain with accuracy but the relative scattering as a function of angle has been measured. Fig. 10 summarizes results obtained by various research workers in different types of water and for different wavelengths of light. It appears that the magnitude of the scattering may vary greatly with the concentration of particles but that the shape of the scattering function (vs angle) does not change significantly. It also appears that the scattering function does not vary greatly with wavelength, a fact which might be surmised from the large size of the particles present in ocean water.

4 THE LIGHT ENVIRONMENT EXPERIENCED BY THE FISH

From the preceding discussion of research results it can be concluded that the light environment experienced by deep-swimming fish is a kind of monochromatic fog. In clear, deep, oceanic water, such as the Gulf Stream, the fog will be an intense blue with a horizontal visibility that might reach to 40 m and a vertical reflectance ratio (for irradiance) of about 10 percent. In deep ocean water containing phytoplankton, the fog would be green. The horizontal visibility might be reduced to 10 m (or even less at high concentrations of phytoplankton) and the vertical reflectance ratio would be about 2 percent. Visibility, i.e. the ability to see objects, is limited in any environment by two quite different phenomena. The first of these is the inherent capability of the eye under consideration. In this respect the human eye has been studied extensively but very little is known about the contrast sensitivity of the eyes of fish, or, for that matter, about the eyes of any animal. The second phenomenon is the physical degeneration of contrast by the presence of scattered light between the object and the observer and the loss of object contrast due to the scattering of radiant flux out of the bright portions of the object and into regions in front of the dark portions of the object. This reduction of visual contrast of objects that might be predators or prey is, for the fish, probably the most important feature of his environment.

TABLE VI - Average values of the diffuse-attenuation function for down-walling irradiance of Crater Lake, 5 August 1966. These values represent the lowest irradiance-K values to be expected in natural waters

$\lambda(\text{nm})$	$K(1/\text{m})$	$\lambda(\text{nm})$	$K(1/\text{m})$	$\lambda(\text{nm})$	$K(1/\text{m})$
350	0.049	470	0.0233	590	0.1450
360	0.043	480	0.0241	600	0.1833
370	0.038	490	0.0249	610	0.223
380	0.033	500	0.0259	620	0.272
390	0.028	510	0.0276	630	0.282
400	0.0238	520	0.0291	640	0.291
410	0.0216	530	0.0301	650	0.308
420	0.0202	540	0.0322	660	0.317
430	0.0190	550	0.0338	670	0.329
440	0.0180	560	0.0354	680	0.338
450	0.0172	570	0.0373	690	0.354
460	0.0166	580	0.0401	700	0.373
	0.0159		0.0422		0.401
	0.0158		0.0437		0.422
	0.0159		0.0445		0.437
	0.0162		0.0452		0.445
	0.0169		0.0477		0.452
	0.0183		0.0500		0.477
	0.0201		0.0533		0.500
	0.0212		0.0565		0.533
	0.0218				0.555
	0.0225				

TABLE VII - Diffuse attenuation coefficients for water containing phytoplankton

	Rich in phytoplankton	Abundant phytoplankton	Excessive phytoplankton
352	0.363	0.511	0.775
362	0.320	0.492	0.744
371	0.290	0.461	0.732
381	0.260	0.455	0.735
391	0.247	0.445	0.738
401	0.226	0.437	0.724
411	0.219	0.447	0.733
420	0.205	0.428	0.719
430	0.193	0.424	0.703
440	0.182	0.402	0.686
450	0.167	0.371	0.615
459	0.159	0.349	0.595
469	0.140	0.314	0.558
479	0.122	0.277	0.513
488	0.111	0.261	0.483
498	0.107	0.271	0.460
508	0.104	0.276	0.447
518	0.094	0.271	0.427
527	0.103	0.256	0.403
537	0.108	0.246	0.379
547	0.114	0.249	0.352
557	0.105	0.247	0.317
566	0.109	0.232	0.303
576	0.130	0.239	0.310
586	0.189	0.271	0.356
596	0.256	0.345	0.418
605	0.359	0.437	0.491
615	0.380	0.470	0.553
624	0.387		0.572
634	0.404		0.585
644	0.438		0.586
654	0.451		0.624
663	0.474		0.746
673			0.700
683			0.696
692			0.701
702			0.754
712			0.742

Contrast can be described as the difference in brightness between two objects or between two portions of the same object. A fish may see another fish against the scattered light from the water background or he may see dark and light marks on individual fish. In either case a contrast must first exist and this contrast will be generated underwater by the radiant energy available in the underwater light field and by the differences in reflectance of the juxtaposed objects or areas. For a given ocean environment and a given distribution of radiant energy, there will be a maximum value for the contrast of an object against its background. This would be the observed contrast if nothing were acting to degenerate it; that is, we imagine that all the water between the observing eye and the object has been removed and the object can thus be observed against its background without the intervening veil of scattered light that

TABLE VIII - The body of the table gives the fraction of incident radiant energy of the specified wavelength that reaches the indicated depth.

Wavelength (λ)	D e p t h			
	10 m	20 m	40 m	80 m
Clear water				
400	0.842	0.709	0.503	0.253
450	0.818	0.669	0.448	0.200
500	0.723	0.523	0.273	0.0740
550	0.507	0.257	0.0661	0.00438
600	0.107	0.0116	0.00013	*
650	0.029	0.00084	*	*
700	0.0048	*	*	*
Water containing phytoplankton				
400	0.104	0.0109	0.000119	*
450	0.188	0.0354	0.00125	*
500	0.342	0.117	0.0137	0.00019
550	0.320	0.102	0.0105	0.000109
600	0.0773	0.00597	*	*
650	0.0125	0.000156	*	*
700	0.0219	0.00048	*	*
Water rich in phytoplankton				
400	0.0126	0.00016		
450	0.0245	0.00060		
500	0.0665	0.00442		
550	0.0829	0.00687		
600	0.0317	0.00100		
650	0.0050	*		
700	0.0021	*		

* Less than 1×10^{-4}

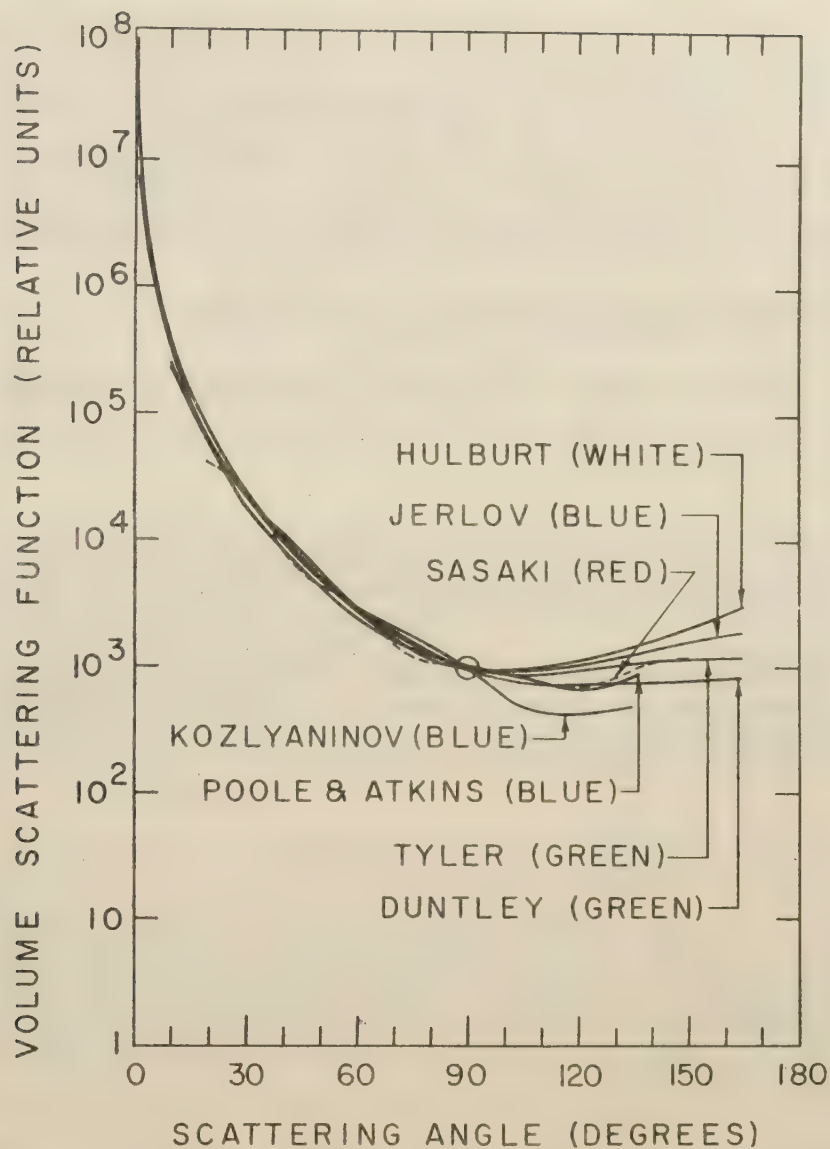


Fig. 10 Comparison of relative volume scattering function obtained by different workers. Each curve is identified with the author and the spectral region for which he obtained the data. Seven different waters are represented. Curves are normalized at 90° (after S.Q. Duntley)

$$C_R = C_0 e^{-(\alpha + k \cos \theta) r}$$

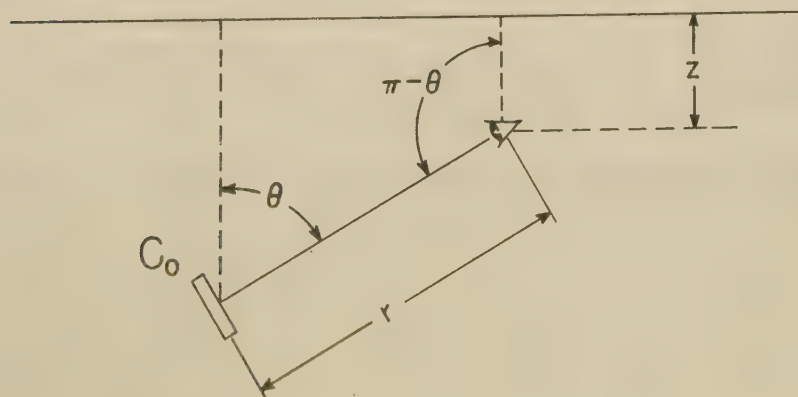


Fig. 11 Geometry to be used in the computation of inherent and apparent contrast

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would otherwise interfere; or, we imagine that we have approached so close that there is no chance for the contrast to be influenced by the infinitesimal thickness of water path remaining. This upper limit for the contrast generated by a given set of circumstances is called the inherent contrast and is given the symbol C_o . From some real distance, R , the contrast actually seen will be less than the inherent contrast and will be called the apparent contrast with the symbol C_r . Numerical values for contrast can be obtained by direct measurements of the brightnesses of the object and of its background and substitution of the values obtained in the following equation

$$C = \frac{B(\text{object}) - B(\text{background})}{B(\text{background})} = \frac{N_o - N_b}{N_b} \quad (7)$$

A fish responds to apparent contrast which can be determined by means of the following equation

$$C_r = C_o e^{-(\alpha + K \cos \theta) r} \quad (8)$$

C_o and C_r in this equation have already been identified as the inherent and apparent contrast respectively of the object against its background. e is the base of the natural logarithm, α is the total attenuation coefficient which was discussed earlier in this paper, k is the diffuse (irradiance) attenuation coefficient also discussed earlier, and θ is the angle shown in Fig. 11. In deep water, Eq. (8) holds for all directions of observation. Nearer the surface of the water, at a depth established by the scattering and absorbing properties of the water itself, Eq. (8) holds for observation directions between the horizontal and the nadir, but for observation directions above the horizontal Eq. (9) is more satisfactory.

$$C_r = C_o e^{-\alpha r} \times \frac{B_1}{B_2} \quad (9)$$

where B_1 is the brightness of the background from the position of the object and B_2 the background brightness from the position of the observer. Equation (9) also applies to the contrast between two areas of different brightness on the same object. Under these conditions B_1 is the inherent brightness of the background area of the object and B_2 is the apparent brightness of the background area of the object. Also C_r is the apparent contrast between dark and light areas of the object and C_o is the inherent contrast contrast between these areas.

It can be seen from Eqs. (8) and (9) that inherent contrast is an essential piece of data for the computation or estimation of apparent contrast. Direct measurements of inherent contrast in the ocean are often inconvenient or impossible. However inherent contrast can be calculated from (i) a detailed knowledge of the distribution of light underwater which can be measured easily and which can also be generalized; and (ii) the gonio-reflecting properties of the object which can be studied in the laboratory.

At the present time complete data on the distribution of light in the ocean are not available, not even for one location. Consequently it is not possible to make a wholly significant calculation of inherent contrast in the ocean. However the method of calculation can be illustrated by making use of the data tabulated in Tables II to V and these tables can also be used to represent any ocean mass having optical properties similar to those of the lake and under similar lighting conditions.

The procedure for calculating inherent contrast from these tables is as follows. Select the table that most nearly applies to the lighting conditions which are of interest to you. You must then specify the direction of the line of sight in terms of the angle from the zenith (θ) and the azimuth angle from the sun (ϕ). These angles are then used to locate in the chosen table, a value of radiance which will be the observed radiance in the direction θ and ϕ . This will also be the background radiance (N_b), (or brightness (B_b)) in Eq. (7). It is next necessary to determine the irradiance falling on a plane at right angles to the line of sight. This is done by summing up all the tabulated radiance contributions on the observer's side of a plane at right angles to the

line of sight. This is done in accordance with the equation

$$H = \sum N \cos \delta \Delta \omega \quad (10)$$

where, δ is the angle between the direction of each N vector and the perpendicular to the plane.

The radiance (N_0) (or brightness $B(\text{object})$) in Eq. (7) can then be estimated from Eq. (11)

$$N_0 = \frac{HR}{\pi} \quad (11)$$

where, H is the calculated irradiance from Eq. (10) and R is the reflectance of the object.

5 REFERENCES

- Cox, C. and W. Munk, Some problems in optical oceanography. J.mar.Res., 14:63-78
1955
- Curcio, J.A. and C.C. Petty, The near infrared absorption spectrum of liquid water.
1951 J.opt.Soc.Am., 41:302-4
- Dawson, L.H. and E.C. Hulburt, The absorption of ultraviolet and visible light by
1934 water. J.opt.Soc.Am., 24:175-7
- Duntley, S.Q., The visibility of submerged objects. La Jolla, California, Scripps
1952 Institution of Oceanography, Visibility Laboratory, Final Report, 74 p.
- _____, Light in the sea. J.opt.Soc.Am., 53(2):214-33
1963
- Hulburt, E.O., Optics of distilled and natural waters. J.opt.Soc.Am., 35:698-705
1945
- Preisendorfer, R.W., Physical aspects of light in the sea. University of Hawaii Press
1964
- Tyler, J.E., Radiance distribution as a function of depth in an underwater environment.
1960 Bull.Scripps Instn Oceanogr., 7(5):363-412
- _____, Observed and computed path radiance in the underwater light field.
1960 J.mar.Res., 18(3):157-67
- _____, Comparison of light distribution above and below water. J.mar.Res.,
1960 18:1080-4
- Tyler, J.E. and R.W. Preisendorfer, Light. In The sea. Ideas and observations on
1962 progress in the study of the seas. Vol.1. Physical oceanography, edited
by M.N. Hill, New York, J. Wiley and Sons, p. 397-451
- Tyler, J.E. and A. Shaules, Irradiance on a flat object underwater. Appl.Opt., 3(1):
1964 105-10

CATCHING CLUPEOID FISH BY PELAGIC TRAWL

by

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Abstract

Aimed fishing with a pelagic trawl to catch herring and pilchards is described. Herring and pilchard were shown to descend from the path of an oncoming trawl, to avoid the ropes round the mouth of the net, and to linger in the mouth of the net when being caught. Fishing techniques to allow for such fish reactions are suggested. The liveliness of shoaling herring under particular conditions is demonstrated, using Asdic, echo sounder and pelagic trawl.

LA CAPTURE DE CLUPEIDES AU CHALUT PELAGIQUE

Résumé

La communication décrit l'emploi, pour la pêche du hareng et du pilchard, d'un chalut pélagique "contrôlé". L'expérience a révélé que ces deux poissons se dirigent vers le bas lorsque l'engin s'approche d'eux, évitent les ralingues de la gueule, et s'attardent dans l'ouverture du chalut lorsqu'ils sont capturés. L'auteur propose diverses techniques de pêche tenant compte de ces réactions du poisson.

Des observations faites en utilisant un asdic, un sondeur à ultrasons et un chalut pélagique montrent la vivacité, dans certaines conditions des harengs rassemblés en bancs.

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LA PESCA DE CLUPEIDOS CON ARTES PELAGICOS

Extracto

Se describe la pesca dirigida con un arte pelágico para capturar arenque y sardina. Se demostró que ambas especies se separan, descendiendo, del arte que se aproxima para evitar los cabos que rodean la boca y que cuando no pueden escapar nadan en ella. Se indican técnicas de pesca que dejan un margen para tales reacciones de los peces. Mediante el empleo de asdic, ecosondas y artes pelágicos se demuestra la vivacidad del arenque que forma cardúmenes en condiciones especiales.

1 INTRODUCTION

This paper is presented as an illustration, from fishing experience, of how fish behaviour - in this case movement of fish in response to the stimulus of an approaching and passing ship and trawl - is linked with the catching process in pelagic trawling. The observations relate to fish of particular species in their particular physiological state at the time and under the particular conditions of water depth, turbidity and illumination. Adaptations of fishing technique to suit the pattern of behaviour of these fish in the vicinity of the trawl are suggested.

2 GEAR AND FISHING CONDITIONS

The observations reported here were all made from the research trawler CLIONE (42 m.b.p., 960 b.h.p.); they cover spawning herring in the late summer fishery in the central North Sea off the Yorkshire coast, mature filling pilchards in the late winter off south-west England, and full herring in summer in the northern North Sea at Shetland.

The trawls used were, off Yorkshire and south-west England, an 800 mesh two-panel Engel net with 55 m bridles and Süberkrüb otter boards, and, off Shetland, a 1200 mesh four-panel Engel net with 73 m bridles and Süberkrübotter boards. They were always fitted with a headline transducer showing the gape and depth of the net, and sometimes with a multiple transducer apparatus involving five transducers all facing in different directions, from the headline upwards, downwards and forward, and from the wing-end across and outwards. The opening of the net was about 11 m in gape and spread.

Fishing was in daylight only, with the water fairly clear off Yorkshire and very clear off south-west England and at Shetland. Trawling depths were mostly between 35 and 65 m.

3 OBSERVATIONS

The early fishing trials were done in the summer of 1963 off the Yorkshire coast where the technique employed was as follows. The shoals of herring were first found by echo-sounder and marked on the Decca plotter; the trawl was then shot (allowing approximately the right length of warp out to fish the trawl at the depth in which the fish had been found, while towing at the normal trawling speed of about 3-3½ knots) and towed towards the fish; the shoal of fish was seen on the towing ship's vertical echo-sounder and its exact depth and thickness noted, and then the depth of the trawl (as indicated by headline transducer) was adjusted to be the same as that of the fish by sudden dropping or increasing of engine revolutions, followed by easing up or down of revs to maintain the net at the required steady depth. Knowing the distance between ship and trawl and the towing speed, time was allowed for the net to come to the observed position of the fish, and they were then seen by the headline transducer to be caught or missed. If the multi-directional transducer system was in operation, it was possible to observe how they were missed.

This technique soon showed that, when the shoals of spawning herring were fairly small, catching was most successful when the trawl was aimed at the apparent bases of the shoals rather than at the tops of them.

Unfortunately the trace records of the first trials were accidentally destroyed. The next trials were made on shoals of pilchards off south-west England in March 1964, and some of the results are illustrated in Fig. 1. This figure shows photographs of the echo-traces of shoals as seen from the towing ship, and, immediately below each, the same shoal as recorded from the headline transducer; the position of the trawl at any time is indicated by two broken lines, representing the paths of headline and groundrope. On each of stations 2 and 3, the trawl was aimed at nine shoals of fish, which were seen entering the net (at station 2, shoals 4, 7 and 9, and at station 3, shoals 6 and 9) and being missed by the trawl.

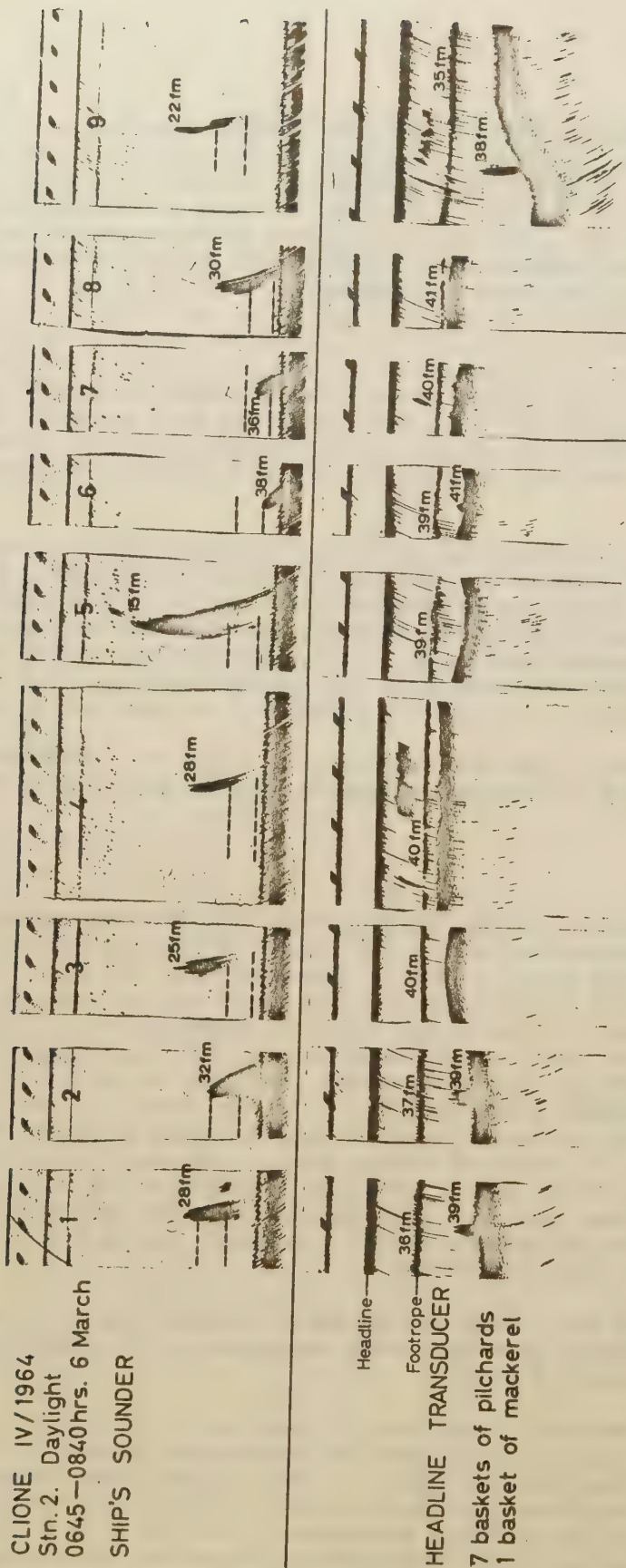


Fig. 1 Shoals of pilchards, as seen by echo-sounder from the towing trawler (upper traces) and from the headline of the trawl (lower traces). The position of the trawl relative to the sea-bed is indicated by dotted lines superimposed on the upper traces. (Continued)

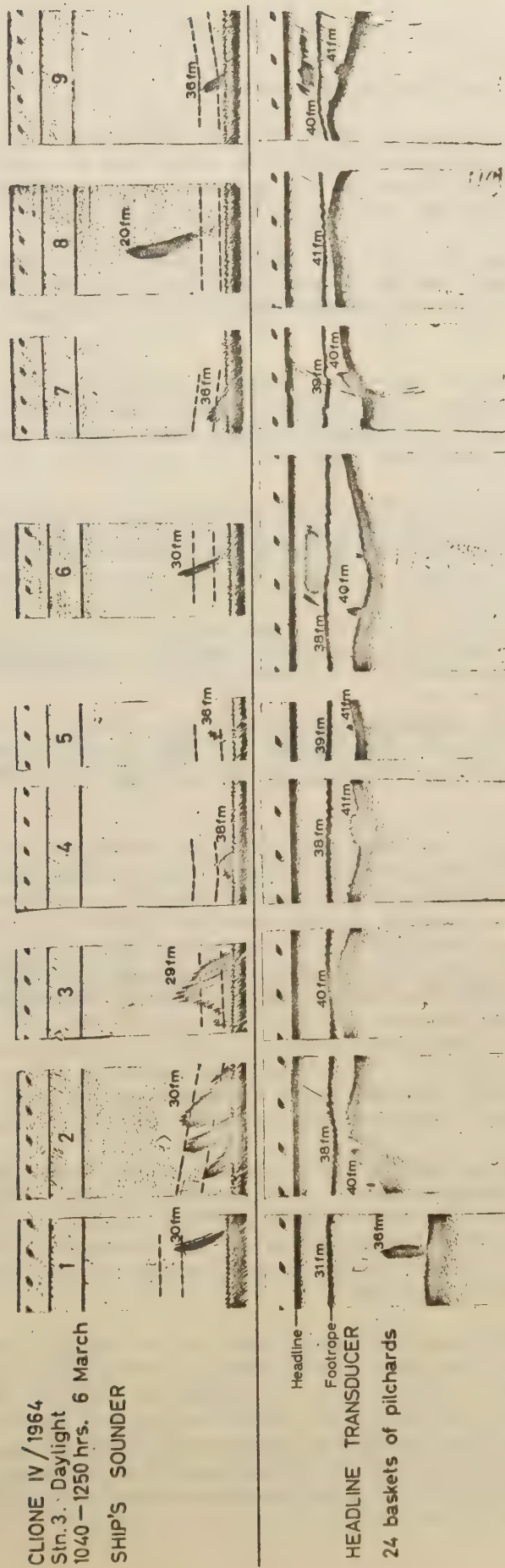


Fig. 1 (continued).

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There are five features of particular interest:

1. When the trawl was aimed at or close above the top of shoals, no fish were seen entering the net, but they were frequently seen well below the net, deeper than when passed over by the towing ship, and close to the bottom, having descended away from the trawl (station 2, shoals 1 and 2; station 3, shoals 1, 2 and 5).
2. When fish were seen entering the net, it was also seen that a part of the shoal aimed at had avoided the trawl and was to be seen well below it and close to the bottom (station 2, shoals 4, 7 and 9). The shoals had been widely split horizontally by the trawl.
3. Wherever fish were seen near to the trawl, they were always well clear of the headline and footrope of the net, either concentrated towards the middle of the net opening or at least 4-6 m below the footrope, presumably being aware of the presence of those ropes and their attachments, and avoiding them.
4. It was noticed that, whereas the towing ship passed over a shoal in a few seconds (and the cone-shape of the sounder beam will have increased this apparent time), when some of that same shoal was seen in the mouth of the net it was seen there for 1½-2 minutes, whilst other parts of the shoal escaping beneath the trawl were again passed over in a few seconds (see especially station 2, shoals 4 and 9 and station 3, shoals 6 and 9). The inference from this is that the fish between the trawl headline and footrope positioned themselves from these and other parts of the net, and swam along some way with the trawl.
5. The most successful catching technique for shoals appearing as fairly compact and small within five fathoms of the bottom was to dip the trawl towards them with the footrope passing within 2 m of the bottom, and to increase speed when fish were seen in the mouth of the net.

Figure 2 is similar to Fig. 1 but is a photograph of traces from later fishing, this time on spawning herring off the Yorkshire coast. Two of the features from the trials on pilchards were again clearly shown; the fish kept well clear of the headline and footrope and, whereas the towing ship passed over the shoal in 2 minutes, the herrings remained in the mouth of the trawl for 5 minutes. These two features indicate that: (a) size of net mouth opening of a pelagic trawl is of prime importance, and (b) increasing towing speed when the net has entered the shoal should avoid or reduce escapes of fish from the mouth of the net. On the subject of the size of the net mouth opening it would appear that, if fish keep about 3 m away from the ropes, then it is probable that, for a 9 m square (81 m^2) net, only the centre 9 m^2 is presented as a clear catching path for the fish, whereas for a somewhat larger net, say 15 m square (225 m^2), some 81 m^2 or nine times more, is presented as a clear path for the fish.

In the summer of 1966, herring shoals were located at Shetland, and these proved very difficult to catch in the pelagic trawl. The impression gained was that the shoals, which appeared as the dense plume type on the echo sounder, were of very lively and active herring, and that they quickly became aware of the presence of the trawl and were able to avoid it easily. An exercise involving the use of Asdic was mounted in order to try to substantiate the impression.

When the position of solid shoals had been fixed on the Decca plotter the ship re-traced her course, searching for them again with Asdic. Several runs over the shoals were made both at full speed and at half speed, and then the pelagic trawl was towed through them. On all of the runs the ship was "homed" on to the shoals by the use of Asdic. Many of the shoals were first located at ranges of 800-1000 m. No attempt was made to alter course towards a shoal unless it was at least 300 m away when first located, and the sharpest alteration in course towards a shoal was 50° when steaming

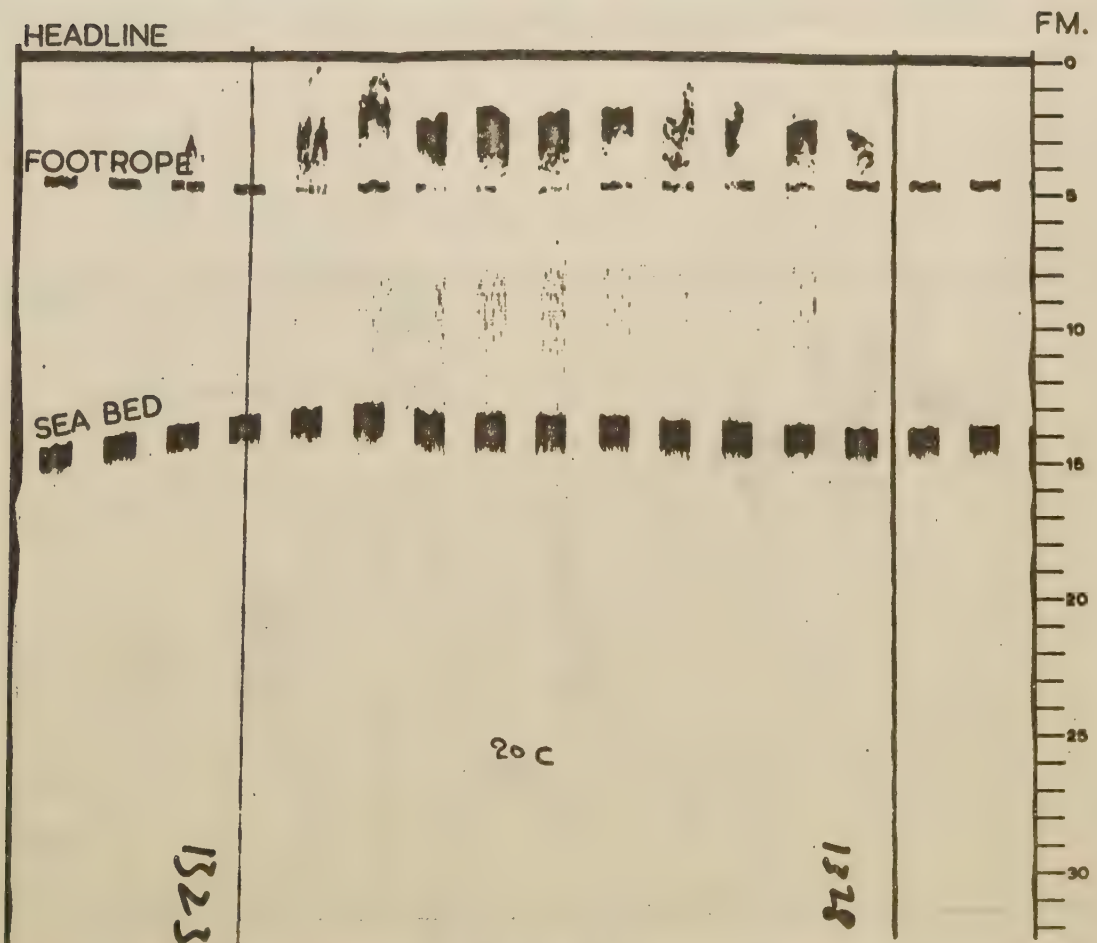
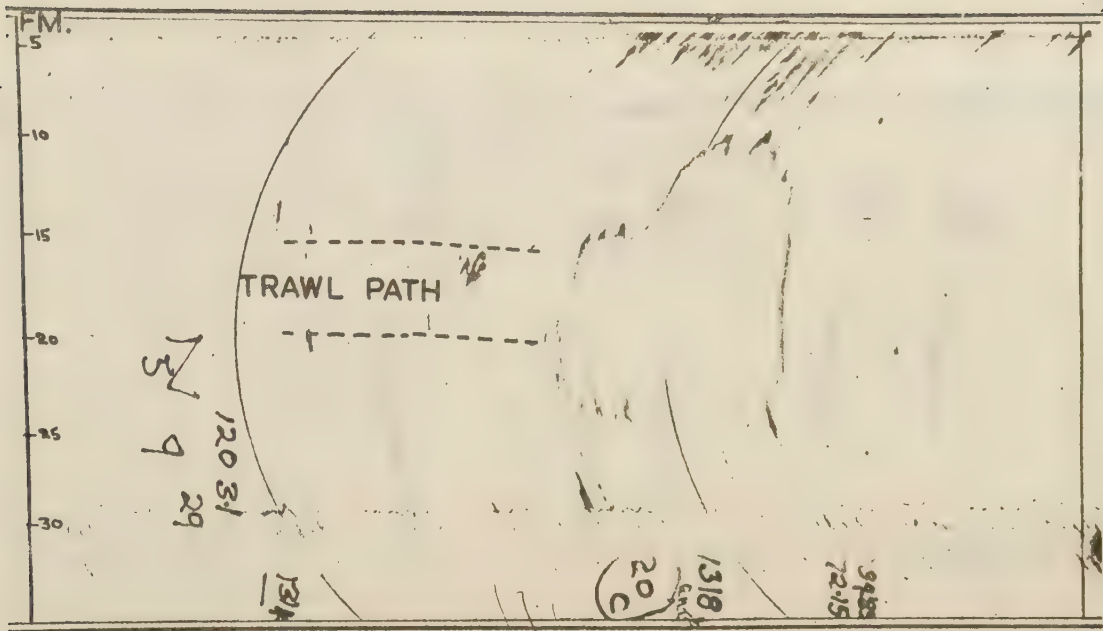


Fig. 2 A shoal of spawning herring as seen by echo-sounder from the towing trawler (upper trace) and from the headline of the trawl (lower trace). The dotted line effect is due to the deliberate intermittent firing in the vertical plane of only one of several transducers fitted to the trawl at the time.

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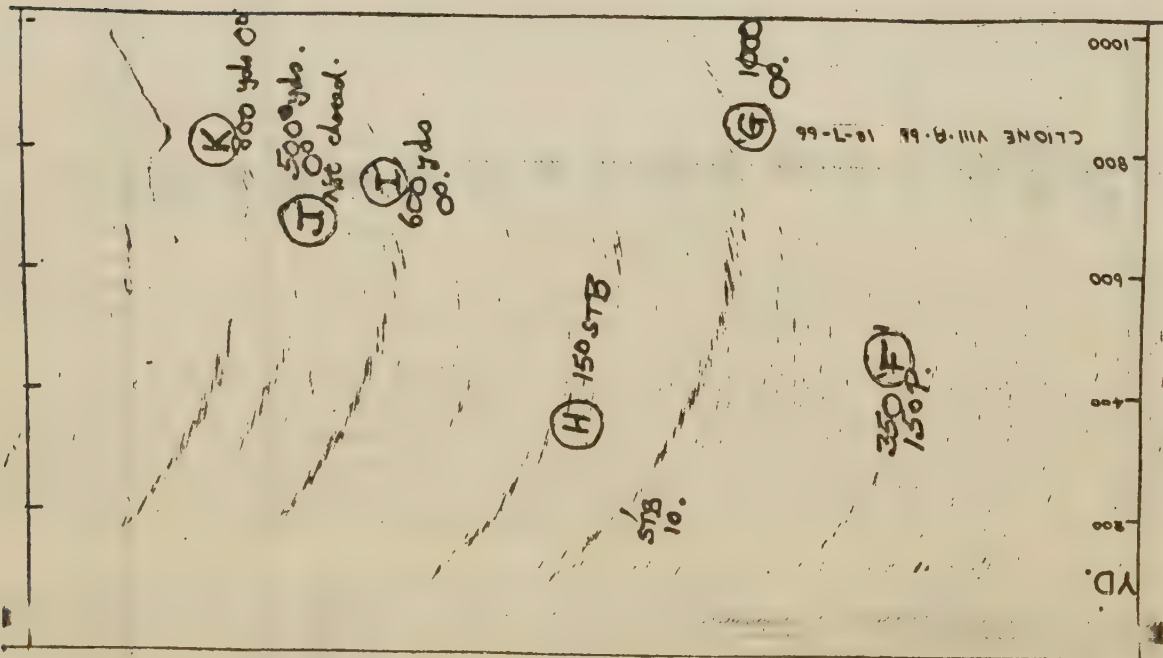
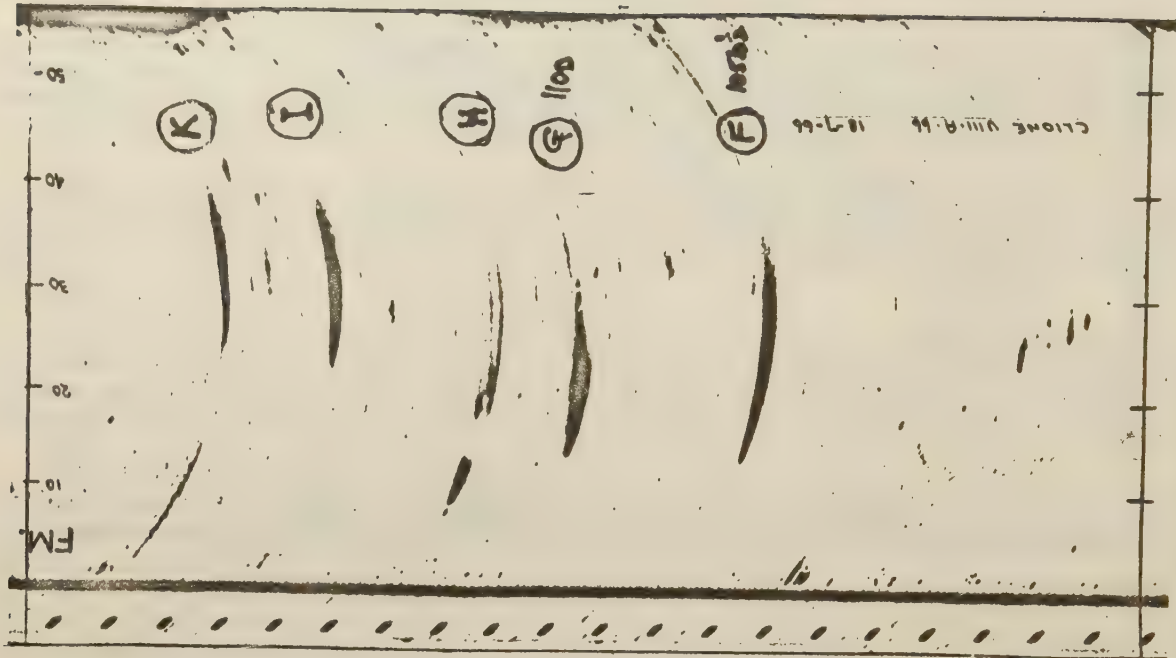


Fig. 3 Shoals of Shetland herring as seen by Asdic (left) and by echo sounder (right). The shoals located by Asdic are lettered - and the appropriate letters are applied to the shoals seen directly below the ship.

TABLE I - Record of success in manoeuvring R.V. CLIONE to pass over herring shoals located by asdic

Ship action and speed	Asdic contacts			Shoals subsequently seen on ship's sounder				Shoals subsequently seen from trawl headline transducer			
	Ahead	Off ship's course	Total	Originally ahead	Originally off ship's course	Total	% Success	Originally ahead	Originally off ship's course	Total	% Success
Steaming free 10 kn (full-speed)	15	13	28	12	11	23	82				
Steaming free 5 kn (half-speed)	9	6	15	6	5	11	75				
Trawling 3-4 kn	10	13	23	6	1	7	30	1	0	1	4

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free and 30° when trawling; the majority of the shoals hunted were within 20° of the ship's heading. Figure 3 shows traces as recorded by both the Asdic and echo-sounder from the same shoals. Despite careful manoeuvring of the ship towards Asdic-located shoals, it was not always possible to bring the ship over the shoal and it was even more difficult to bring the trawl into contact with the shoal. A summary of the results is given in Table I, in which distinction is made between shoals located at full speed, at half-speed, and while trawling, and success in homing the ship on to shoals is expressed in terms of the percentage of shoals detected by Asdic, that were approached and actually passed over by the ship.

Allowing for some mechanical defects of the Asdic set and for the operator being out of practice, the 82 percent success in homing the ship on to shoals while steaming free at 10 knots was considered to be satisfactorily close to the nearly 100 percent success that might have been expected from a skilled operator with perfect equipment at that speed. It was anticipated that at 5 knots the homing of the ship over shoals would be easier, since more time was available for checking bearings and for manoeuvring the ship, but in fact the success rate at the reduced speed was somewhat lower (73 per cent). The success rate while trawling was much lower (30 percent), and of those shoals that the ship did pass over, only one eventually reached the net and was partially caught. Once the trawl has been shot the ship becomes less manoeuvrable, and the positioning of the trawl correctly to encounter the shoal calls for an intimate knowledge of the relative motions of the ship and trawl. But the skipper and fishing crew of R.V. CLIONE were not without experience of pelagic trawling, being those who had made the earlier trials on spawning herring off Yorkshire and on pilchards off south-west England; so it is reasonable to suppose that even after allowing for improvement from better knowledge of relative motions, the percentage success of homing while trawling would still be far below that while steaming free, and that the number of encounters between trawl and shoals would not have been greatly increased.

The pattern of events when an Asdic-located shoal was missed by the ship was most frequently that, after the shoal was first located and the ship's course altered towards it, the echo would be seen on bearing straight ahead and the range on this bearing would close steadily until it had come down to about 100-200 m. Then, despite changing the Asdic to wide beam, the echo would be lost for a few seconds, to be re-discovered some $5-10^\circ$ off the ship's unaltered heading. Even another alteration of course on to the new bearing of the shoal seldom resulted in the ship passing over the shoal.

A conclusion drawn from these experiences was that the summer Shetland herring shoals sensed the approach of the fishing trawler and trawl and took avoiding action, both before the trawler reached them and in the interval between the passage of the trawler above them and the arrival of the trawl at their level. In this, their behaviour was markedly different from that of spawning herring off Yorkshire. A further provisional conclusion was that the Shetland herring took little or no notice of a ship running free and fast, but avoided a slow-moving one and especially a labouring one towing a trawl.

It is to be noted that purse-seine fishermen are well aware of the active behaviour of herring in certain fisheries and alter their fishing technique accordingly. For instance, the shape of the "ring" made in pursing is varied according to swimming speed and direction, and the timing of pursing, relative to the sinking of the net, is varied according to the rapidity of descent of shoals.

* * * * *

Acknowledgement

The author is indebted to Mr. J.P. Bridger for his assistance in this work.

PRELIMINARY RESULTS FROM A FISHERY
RESEARCH SURVEY OF WEST AFRICAN WATERS

by

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Abstract

When surveying West African waters between the Canaries and the Cape Verde Islands 22 June to 10 July 1967, the Brazilian research vessel PROF. W. BESNARD made some observations on the distribution and behaviour of fish concentration by applying acoustic methods.

Sonar detection of pelagic shoals was obtained by daytime. During the night the shoals dispersed and appeared on the echo sounder as a continuous scattering layer.

The echo recordings showed the highest density on and along the edge of the continental shelf with the main concentration between 17°N and 21°N. In this area a large international commercial trawling fleet operated, and by analysing the composition of their catches, it is assumed that the echo recordings represented Sardinella aurita (gilt sardine), Caranx sp. ("yellow mackerel"), and Trachurus trachurus (horse mackerel). The gilt sardine and the "yellow mackerel" were both in pre-spawning condition and it is likely therefore that spawning takes place during the summer months.

Hydrography as well as plankton observations were carried out in order to gain knowledge on environmental conditions.

RESULTATS PRELIMINAIRES DE RECHERCHES
HALIEUTIQUES AU LARGE DE L'AFRIQUE

Résumé

Lors d'une campagne effectuée dans les eaux ouest-africaines entre les Canaries et les îles du Cap-Vert du 22 juin au 10 juillet 1967, le navire de recherche brésilien PROF. W. BESNARD a fait quelques relevés acoustiques sur la répartition et le comportement de rassemblements de poissons.

La détection sonar de bancs pélagiques a eu lieu de jour. La nuit, les bancs se dispersaient et apparaissaient sur l'échogramme sous forme de couche diffusante continue.

Les enregistrements ont révélé que les plus fortes concentrations se situaient au-dessus du plateau continental et le long du rebord continental, avec un maximum entre les latitudes 17° et 21°N. Une nombreuse flotte commerciale de chalutiers de diverses nationalités opérait dans ce secteur, et après avoir examiné la composition

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de leurs prises, on peut avancer l'hypothèse que les échogrammes représentaient des tracés de Sardinella aurita (sardinelles ou allaches), de Caranx sp. (carangues) et de Trachurus trachurus (chinchards). Tant sardinelles que carangues se trouvant au stade de pré-ponte, il est probable que le frai a lieu durant les mois d'été.

Des observations hydrographiques et des prélèvements de plancton ont été effectués afin de rassembler des données sur les conditions ambiantes.

RESULTADOS PRELIMINARES DE UNA INVESTIGACION PESQUERA EN AGUAS DEL OESTE DE AFRICA

Extracto

La distribución y reacciones de concentraciones de peces fueron observadas acústicamente por el barco para investigaciones brasileño PROF. W. BESNARD mientras, del 22 de junio al 10 de julio de 1967, estudiaba las aguas al oeste de Africa, entre las Islas Canarias y las de Cabo Verde.

Durante el día se localizaron con sonar cardúmenes pelágicos, que se disgregaban durante la noche y aparecían en la ecosonda como una capa de dispersión continua.

Los registros de la ecosonda indicaban que las mayores densidades se encontraban junto al borde de la plataforma continental y encima de él, con la concentración principal entre los 17° y los 21° de latitud norte. En esta zona trabaja una gran flota de arrastreros de diversas naciones y analizando la composición de sus capturas se deduce que los registros de las ecosondas representaban Sardinella aurita (alacha), Caranx sp. (especies de jurel) y Trachurus trachurus (jurel).

Las alachas y los carángidos no habían desovado todavía, por lo que se supone que el desove ocurre durante el verano.

Para adquirir conocimientos sobre las condiciones del ambiente se realizaron observaciones hidrográficas y del placton.

PHOTOGRAPHIC OBSERVATIONS ON REACTIONS OF
FISH AHEAD OF OTTER TRAWLS

by

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Abstract

Observations were recorded by a multi-exposure underwater camera and flash attached to the headline of an otter trawl. Studies were conducted by day and night in two areas of the Northwest Atlantic. In general, Atlantic cod and haddock ahead of the footrope swam near bottom. There was no suggestion of attempted escape over the headline. During the day most cod and haddock swam ahead of the trawl in the general direction of the tow. The greater the number of cod observed at one time, the more consistent was their direction of swimming. Instances of cod swimming in the direction of tow were less frequent after dark. Haddock oriented to the direction of tow more frequently at night. Most flatfish, longhorn sculpin, ocean pout, and skate remained on bottom ahead of the footrope.

Swimming speeds and distances necessary for fish to avoid capture ahead of the footrope were calculated for otter trawls of different size. Results suggest cod and haddock can escape provided they swim in linear paths at angles of 10° to 30° degrees to the direction of tow and that for each angle the correct swimming speed is followed. Winter flounders appear able to swim from the smallest trawl. However, their behaviour ahead of the trawl suggests few make the attempt. Longhorn sculpin and ocean pout appear unable to escape by swimming from any of the trawls.

^{1/}Based on research conducted at the Fisheries Research Board of Canada's Biological Station in St. Andrews, New Brunswick.

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OBSERVATIONS PHOTOGRAPHIQUES SUR LES REACTIONS DES POISSONS SE TROUVANT SUR LA TRAJECTOIRE D'UN CHALUT A PANNEAUX

Résumé

Les observations, faites au moyen d'un appareil photographique sous-marin à prises de vues multiples équipé d'un flash électronique et fixé à la corde de dos d'un chalut à panneaux, ont été effectuées de jour et de nuit dans deux secteurs de l'Atlantique Nord-Ouest. En général, la morue de l'Atlantique et l'églefin se trouvant devant la ralingue inférieure du chalut nagent près du fond, et ne semblent pas tenter d'échapper en passant par-dessus la corde de dos. Durant la journée, la plupart des morues et des églefins nagent en avant du chalut, dans la direction générale du trait. Plus le rassemblement de morues est important, et plus s'affirme la direction de leur nage. La nuit tombée, on relève moins de cas de morues se déplaçant dans le même sens que le chalut. De nuit, l'églefin s'oriente plus fréquemment dans la direction du trait. La plupart des poissons plats, des "longhorn sculpins" (Myoxocephalus octodecemspinosus), des "ocean pouts" (Macrozoarces americanus), et des raies demeurent sur le fond devant le bourrelet.

On a calculé, pour des chaluts à panneaux de diverses tailles, les vitesses de nage et les distances nécessaires pour que les poissons se trouvant immédiatement devant le bourrelet puissent éviter le filet. La morue et l'églefin devraient pouvoir échapper s'ils nagent suivant une ligne droite faisant avec la direction du trait un angle de 10° à 30° , et à une vitesse adaptée à l'angle choisi. Il semble que les faux carrelets (Pseudopleuronectes americanus) puissent éviter en nageant le plus petit des chaluts, mais d'après leur comportement devant l'engin, seul un petit nombre fait la tentative. Les "longhorn sculpins" et les "ocean pouts" paraissent incapables d'échapper à aucun des chaluts.

OBSERVACIONES FOTOGRAFICAS DE LAS REACCIONES DE LOS PECES DELANTE DE LOS ARTES DE ARRASTRE DE PUERTAS

Extracto

Se hicieron observaciones con una cámara fotográfica submarina de diversas exposiciones y un flash montados a la relinga de corchos de un arte de arrastre de puertas. Los estudios se realizaron de día y de noche en dos zonas del noroeste del Atlántico. En general, el bacalao y el eglefino que se encuentran delante de la relinga de plomos nadan cerca del fondo. No se observaron tentativas de escapar por encima de la relinga de corchos. Durante el día, casi todo el bacalao y el eglefino nadaban delante del arte y en su dirección. Cuanto mayor era el número de bacalaos observados en un momento, más constante era la dirección de sus movimientos. Los casos de bacalao que nadara en la misma dirección del arte eran menos frecuentes después de la oscuridad. El eglefino se movía en la dirección del arte más frecuentemente de noche. Casi todos los peces planos, rayas, cabrachos y fanecas se mantenían en el fondo delante de la relinga de plomos.

Se calcularon para artes de arrastre de puertas de diversas dimensiones las velocidades de natación y distancias necesarias para que los peces evitaran la captura inmediatamente delante de la relinga de plomos. Los resultados indican que el bacalao y el eglefino pueden escapar si nadan en línea recta y formando ángulos de 10° a 30° con la dirección del arte y si para cada ángulo mantienen la velocidad exacta. Las plati-
jas parecen ser capaces de escapar de los artes más pequeños, pero su comportamiento delante de éstos indica que pocas tratan de hacerlo. El cabracho y la faneca no parecen ser capaces de escapar de ninguno de los artes.

1 INTRODUCTION

Knowledge of fish behaviour ahead of an otter trawl is an important step in assessing the gear's performance. Without this information attempts to design more efficient gear would, at best, meet with limited success. In the sea, direct underwater observations by divers equipped with cameras is perhaps the most satisfactory where conditions are suitable. Generally depth, low light intensity and high towing speeds are forbidding to divers. Recently, Blaxter and Parrish (1965) observed reaction of marine fish to moving nets and parts of nets in shallow tanks. Indirect underwater observations can be made by movie cameras, television (Clark, Livingstone and Crossen, 1959), still cameras (Craig and Priestly, 1963) and high frequency echosounding (Welsby, Blaxter and Chapman, 1963).

Behaviour studies in the Northwest Atlantic, were conducted with a still camera and electronic flash, adapted for observations ahead of the footrope of an otter trawl. It was felt continuous artificial lighting would be necessary to successfully operate movie or television cameras and that this would influence behaviour particularly at low light intensities (Blaxter and Parrish, 1965). In addition hydrodynamic resistance of cables required for underwater lights makes observations impractical. Thus, the still camera was selected in spite of the considerable time delay between the event and its observation.

Haddock (Melanogrammus aeglefinus), Atlantic cod (Gadus morhua), and flatfish, including winter flounder (Pseudopleuronectes americanus) and American plaice (Hippoglossoides platessoides) were most common in photographs with fewer observations of Atlantic herring (Clupea harengus harengus), Atlantic mackerel (Scomber scombrus), skates (Raja sp.), ocean pout (Macrozoarces americanus) and longhorn sculpin (Myoxocephalus decemspinosus).

2 METHODS

The camera and flash chosen were a model 200 underwater camera and model 210 underwater light source manufactured by EG&G Inc. Limitation of weight and orientation of equipment demanded a special aluminum housing be designed which is described in detail by Carrothers (1967) and illustrated in Fig. 1a and 1b. Features of the camera include:

1. At normal towing speeds the induced drag of the streamlined housing for the camera and flash on the headline of an otter trawl is too low to cause appreciable distortion to the net (Carrothers, 1967).
2. The camera and light are completely self contained requiring no external equipment.
3. The camera automatically takes pictures at about 12-sec intervals and will hold 30m of 35mm film, equivalent to 500 frames.
4. Each frame is identified by a photographic data record which includes frame number, depth, time, date, area, vessel, and type of film.

Generally, the camera unit was shackled to the centre of the headline of an otter trawl. Mounted in this way, the camera takes pictures of bottom some 2 or 3 m ahead of the footrope through clear acrylic windows located on the lower side of the case (Fig. 1c).

Three research vessels were used in the study. The C.G.S. A.T. Cameron carries a number 41 courlene otter trawl and for photographic observations towed at 1.75m/sec. The M.V. Harengus is equipped with a number of 36 courlene otter trawl and customarily tows at 1.75m/sec. The smallest net is carried by the M.V. Mallotus, a number 3/4 35 courlene otter trawl and is towed at 1.5m/sec. A number 41 trawl has a 30m footrope and about a 24m headline. The headline height is estimated at 2m and wingspread 13m. A number 36 trawl has a footrope and headline of approximately 24 and 18m respectively. Headline height is about 3m and wingspread, 10m. A number 3/4 35 otter trawl has a footrope of 15m and headline of 12m. The headline is about 2m from bottom and wingspread estimated at 9m. The field of view with the camera on the headline of a number 36 otter trawl is about $1.35\text{m}^2 (1.5 \times 0.9\text{m})$ and slightly smaller on a 3/4 35 or 41 trawl.

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Photographic observations were made mainly in two areas, Miscou Island in the Bay of Chaleur ($48^{\circ}10'N, 64^{\circ}30'W$) and Passamaquoddy Bay in the Bay of Fundy ($45^{\circ}N, 67^{\circ}W$). Tows in the Miscou Island area were made by day and night during October 1965 by the Harengus. In Passamaquoddy Bay tows were made by day and night during April, August and November 1965, and June 1967. Tows during April and November were made by the Harengus, those during August and June by the Mallotus. Most tows in the Miscou Island and Passamaquoddy Bay areas were made at depths between 30 and 50m. A few tows were made on Banquereau Bank ($46^{\circ}28'N, 59^{\circ}18'W$), during March 1965 by the A.T. Cameron. The length of tow was generally 1h. Some 30-min tows were made particularly in areas restricted by rough or uncertain bottom.

In the experiments conducted to date, attention has been directed to orientation of fish ahead of the middle of the footrope. Four categories, each based on the angle fish were swimming relative to the direction of tow, were used to describe orientation. If the angle was not more than 10° , fish were regarded swimming in the direction of tow. A second category included fish swimming at an angle between 10° and 40° to the direction of tow, hereafter referred to as swimming diagonally to the tow. Fish were considered swimming towards the wings of the trawl when the angle was 40° to 90° and into the trawl when the angle was greater than 90° . Photographs were separated according to number of fish per frame; individuals, groups of 2 to 4, and groups of 5 or more. Orientation of each fish within the group was recorded and a note made on the homogeneity in direction of swimming within the group. Further, orientation ahead of the trawl by day was compared with that after dark. Attention was given also to the distance of fish from the sea floor and whether they appeared to be actively swimming.

3 RESULTS

3.1 Haddock

Observations on haddock were made in Passamaquoddy Bay in August and November 1965 and June 1967 with the camera unit attached to a 3/4 35 or 36 trawl. With the number of observations made it was not possible to demonstrate differences in behaviour ahead of the two trawls.

Haddock did not appear to rest on bottom ahead of the trawl but rather actively swam a short distance from bottom. Certainly there was no suggestion of attempted escape over the headline. Although the camera was not in the best position to estimate movements in the direction, it is believed that extensive movements would have been recorded. Most haddock swam within 40° of the direction of tow and of these over half were within a few degrees. Few fish were observed swimming into the trawl. Orientation to the direction of tow among groups of 2 to 4 fish was about the same as that for individuals. After dark, orientation to the direction of tow increased. The results of several tows in which relatively large numbers of haddock were photographed are summarized in Table I. Among photographs with single fish, 41 percent swam in the direction of tow by day and 32 percent diagonally to the tow. Orientation of individuals within groups was similar. After dark over 56 percent of individuals swam in the direction of tow and 28 percent diagonally to the tow. Within groups 52 percent of individuals were headed in the direction of tow and 40 percent diagonally to the tow. Instances of haddock swimming towards the wings were more frequent by day than by night.

3.2 Atlantic cod

Photographic observations were collected off Miscou Island in October 1965 and in Passamaquoddy Bay during April and November 1965. All tows were made by the M.V. Harengus with a number 36 otter trawl. A few tows with a number 41 trawl were made by the C.G.S. A.T. Cameron to the east of Banquereau Bank in March 1965.

Concordant with observations on haddock ahead of the trawl, cod did not rest on bottom by day or night. Rather they actively swam ahead of the trawl, a short distance from bottom.

During hours of daylight most cod were observed swimming ahead of the moving net in the same direction as the tow (Fig.2a). The greater the number of cod observed at one time, the more consistent was their direction of swimming (Fig.2b). Few observations were made after dark. However, instances of cod swimming in the direction of tow appear to be less frequent at this time. Groups of cod were less common at night.

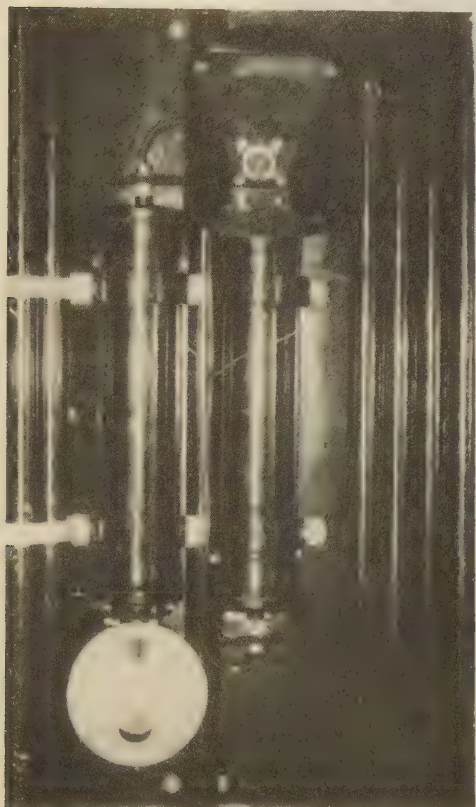


Fig. 1a Camera and electronic flash mounted in aluminium case.



Fig. 1b Camera case opened for inspection of camera and flash

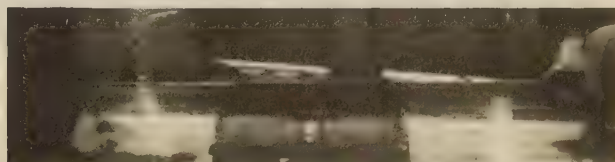


Fig. 1c Camera case illustrating acrylic windows on the lower side

The results of 10 tows made by day are given in Table II. Orientation to the direction of tow increased from 55 percent for single observations to 68 percent for individuals within groups of 5 or more cod. Over 86 percent of all cod were swimming away from the trawl. Few fish were observed swimming towards the wings or into the trawl.

3.3 Flatfish (Winter flounder and American plaice)

Observations on flatfish were made off Miscou Island in October 1965 and in Passamaquoddy Bay in April and November 1965 from a number 36 otter trawl. Additional photographs were taken in Passamaquoddy Bay in August and November 1965 and June 1967 from a 3/4 35 trawl.

Separation of winter flounder and plaice, the most abundant flatfish in catches, often was difficult from photographs. Hence they were treated together. Most flatfish ahead of the trawl remained on bottom (Fig.3a). Of those swimming ahead of the trawl, none

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observed far from bottom and over half were headed towards the wings (Fig.3b). The remainder were about equally divided between the direction of tow and into the trawl. There was no obvious difference in behaviour by day and night. Groups of flatfish were not observed.

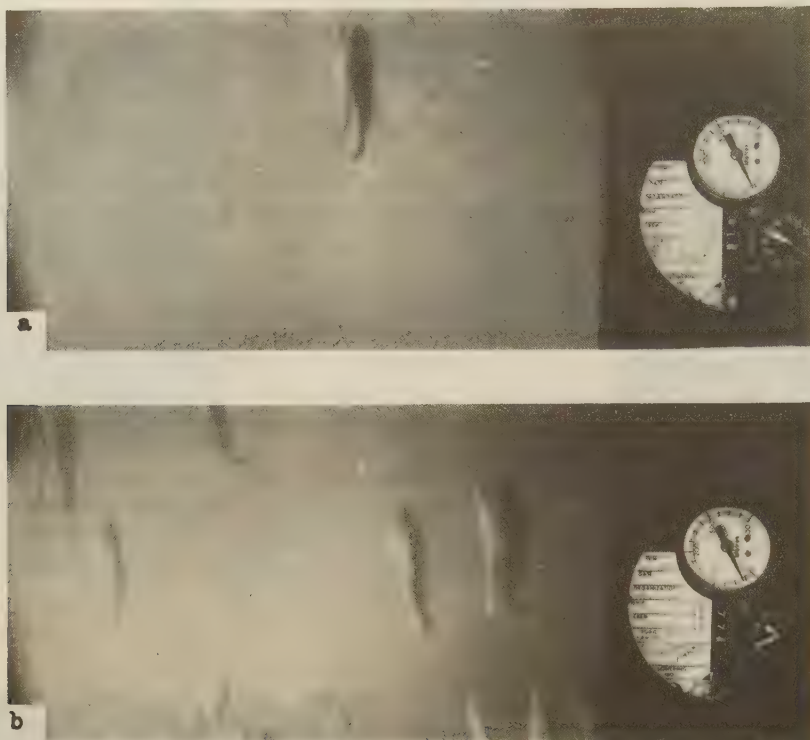


Fig. 2 Atlantic cod swimming in the direction of tow ahead of the footrope of an otter trawl. The photographs were taken in daylight, and as indicated in the data sheets, off Miscou Island in the Bay of Chaleur at a depth of about 30 m.

Above - a single Atlantic cod (a); below - a group of Atlantic cod (b)

3.4 Other species

A few observations were made on other species but in no case are the numbers sufficient to permit more than a general statement.

Atlantic herring and Atlantic mackerel have been observed on a few occasions in daylight tows off Miscou Island and in Passamaquoddy Bay. Observations suggest both species swim further off bottom than cod, haddock, or flatfish and often towards the wings (Fig. 4a and b).

Skates have been observed in daylight tows off Miscou Island and in Passamaquoddy Bay. Generally they swam a short distance from bottom. However instances of skates on bottom were not uncommon. There was no suggestion of orientation to the direction of tow. About equal numbers were observed in each direction.

Longhorn sculpin and Ocean pout were photographed in Passamaquoddy Bay. Most of the sculpins and ocean pouts appeared to rest on bottom rather than swim ahead of the trawl.

Fig. 3 Flatfish ahead of footrope of an otter trawl. The photographs were taken by day in the Miscou Island area in the Bay of Chaleur at a depth of about 30 m

Above - a flatfish on the sea bottom (a)
Below - flatfish swimming toward the wings of the trawl (b)

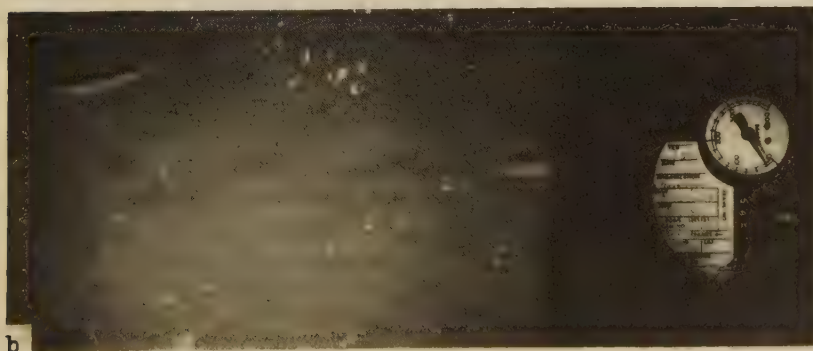
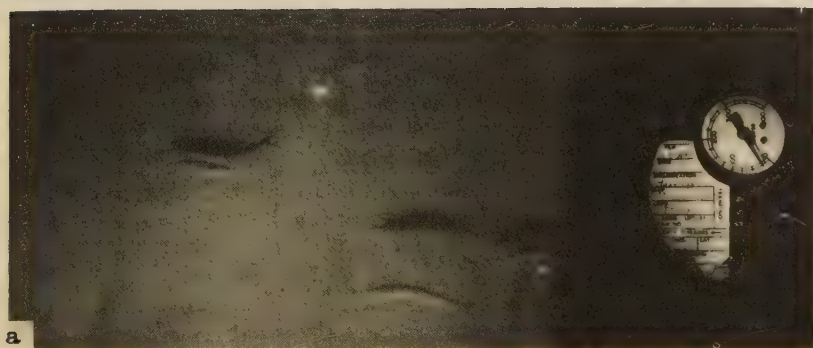
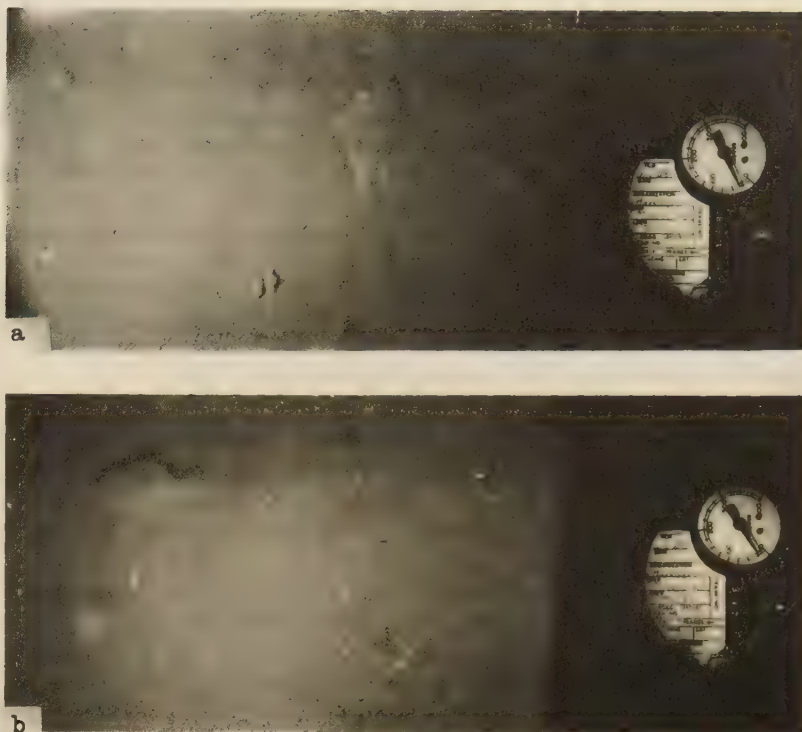


Fig. 4 Fish ahead of the footrope of an otter trawl. The photographs were taken in daylight off Miscou Island in the Bay of Chaleur at a depth of about 30 m

Above - Atlantic herring (a)
Below - Atlantic mackerel (b)

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4 DISCUSSION

In most cases during daylight tows cod and haddock swam ahead of the trawl in the general direction of tow. Presumably both species are herded ahead of the trawl in reaction to some stimulus, visual or non-visual. Blaxter and Parrish (1965) observed herding among marine fish ahead of towed nets and parts of nets in shallow tanks at relatively high light intensities. Fish in the path of the wings were herded inwards towards the centre of the footrope and then swam in the direction of tow. In low light intensities, herding decreased to suggest behaviour was related to visual stimulus. Observations on haddock in the present study are in marked contrast. At night, orientation to the direction of tow was more pronounced than by day. This suggests orientation, at least for haddock, may be related to non-visual stimuli. Noise produced by various parts of the trawl may play an important role. Other factors such as pressure changes or odor may influence behaviour.

Consistent patterns of orientation ahead of the trawl were not observed for flatfish, skate, ocean pout or longhorn sculpin by day or night. Many fish made no attempt to swim from the path of the net. For those that swam there was no evidence of herding in the direction of tow. In contrast among flatfish there was a tendency to swim towards the wings.

The importance of observations on fish behaviour ahead of an otter trawl is, of course, to enhance knowledge on the gear's performance. One of the important questions is whether fish within the bight of a trawl can escape. If so, how? Do they attempt to swim around the wings or dart upwards out of the trawl's reach? Camera observations generally do not fully answer these questions. They do, however, provide a basis from which to work. Photographic observations provided no evidence to suggest fish swim upwards out of the trawl's reach. Further, they indicate orientation of fish which together with information on endurance capacity at various swimming speeds is useful in assessing escape potential. Speeds necessary to escape from the center of the footrope were calculated for 3 sizes of trawls commonly used in the Northwest Atlantic. From the evidence provided by Blaxter and Parrish (1965) it was assumed in the calculations that fish react to a trawl about 3m ahead of the footrope. Calculations were based on a towing speed of 1.8m/sec and are presented in Table III. Only horizontal linear paths of escape, at angles to the stream were considered.

Swimming endurance was determined in an activity chamber modified from that described by Blazka, Volf and Cepela (1960) for cod, winter flounder, longhorn sculpin and ocean pout (Beamish, 1966), and haddock (Chandler, personal communication). Calculated swimming speeds sufficient to escape are above 1.4m/sec, the highest velocity that could be tested with the apparatus used. However, some estimate of maximum distances fish can swim at faster speeds can be derived by extrapolation from the relations given in Beamish (1966) and Chandler (personal communication). Despite the obvious dangers in these extrapolations, the results may be used in a general way to estimate the potential of the different species to escape.

Escape from any of the trawls appears possible for cod and haddock swimming in linear paths at angles of 10 to 30° to the direction of tow provided the correct speed is followed. At 40 to 50°, escape is possible only from the 3/4 35 trawl. In the direction of tow neither species can swim for as much as 2min. Hence escape in this direction is unlikely for all but the new recruits near the end of the tow. Orientation of cod by day indicates that up to 25 percent of those ahead of the footrope have the potential to escape. For haddock escape potential is over 30 percent. Winter flounder appear able to escape only from a number 3/4 35 trawl and then only when swimming at angles between 10 and 40°. Swimming speed dies on longhorn sculpin and ocean pout suggest neither species can escape from the of any of the three trawls regardless of the angle to the tow. Photographic observations suggest most flatfish, longhorn sculpin, and ocean pout in the path of a trawl do not swim but rather remain on bottom. Providing they do not dart upwards at the last instant or are not critically damaged by the footrope, escape seems likely.

TABLE I - Orientation of haddock by day and night immediately ahead of the middle of the footrope of an otter trawl. The data represent observations from five tows by day and seven by night, all made in Passamaquoddy Bay in the Bay of Fundy during late June 1967

Angle between direction of tow and swimming (degrees)		Day		Night	
		(No.)	(%)	(No.)	(%)
(A)	(1) 0-10 (in direction of tow)	54	41	58	56
	(2) 10-40 (diagonally to the tow)	42	32	29	28
	(3) 40-90 (towards wings)	29	22	7	7
	(4) 90 + (into trawl)	6	5	9	9
		<u>131</u>	<u>100</u>	<u>103</u>	<u>100</u>
(B)	(1) 0-10 (in direction of tow)	23	39	47	52
	(2) 10-40	23	39	36	40
	(3) 40-90 (towards wings)	10	17	5	6
	(4) 90 + (into trawl)	3	5	2	2
		<u>59</u>	<u>100</u>	<u>90</u>	<u>100</u>
(A) - 1 fish per photograph		(B) - 2 to 4 fish per photograph			

TABLE II - Orientation of Atlantic cod ahead of an otter trawl. The data summarize photographic observations from 10 tows made during the hours of daylight off Miscou Island in the Bay of Chaleur and in Passamaquoddy Bay in the Bay of Fundy

Angle between direction of tow and swimming (degrees)		Cod	
		(No.)	(%)
(A)	(1) 0-10 (in direction of tow)	89	55
	(2) 10-40 (diagonally to the tow)	46	28
	(3) 40-90 (towards wings)	10	6
	(4) 90 + (into trawl)	18	11
		<u>163</u>	<u>100</u>
(B)	(1) 0-10 (in direction of tow)	93	60
	(2) 10-40	40	26
	(3) 40-90 (towards wings)	6	4
	(4) 90 + (into trawl)	16	10
		<u>155</u>	<u>100</u>
(C)	(1) 0-10 (in direction of tow)	154	68
	(2) 10-40	50	22
	(3) 40-90 (towards wings)	12	5
	(4) 90 + (into trawl)	12	5
		<u>228</u>	<u>100</u>
(A) - 1 fish per photograph		(B) - 2 to 4 fish per photograph	
		(C) - 5 or more	

TABLE III -- Minimum swimming speeds and distances to escape from the bight of three sizes of otter trawl in use in the Northwest Atlantic. Calculations are based on a towing speed of 1.8m/sec. Estimates of maximum distances species can swim at different velocities were extrapolated from the relations given in Beamish (1966) and Chandler (personal communication). For angles in excess of those recorded in the table, swimming speeds to escape were above 8m/sec and assumed beyond the capability of the fish

Trawl size	Angle between path of escape and direction of tow (degrees)	Minimum distance to escape from trawl (m)	Minimum swimming speed to escape (m/sec)	Maximum distance fish can swim at minimum swimming speed required to escape (m)				
				Cod	Haddock	Winter Flounder	Longhorn Sculpin	Ocean Pout
41	0	*	1.8	170	150	70	8	8
	10	37	2.1	140	100	45	7	1
	20	19	2.8	90	60	22	3	-
	30	13	4.2	40	30	7	-	-
36	0	*	1.8	170	150	70	8	8
	10	31.7	2.3	120	90	35	6	-
	20	16.1	3.3	65	50	15	-	-
	30	11.0	6.7	25	13	3	-	-
3/4 35	0	*	1.8	170	150	70	8	8
	10	26	1.9	150	110	60	7	1
	20	13	2.4	110	85	30	6	-
	30	9	3.0	70	55	18	3	-
	40	7	4.1	50	30	10	-	-
	50	6	6.7	25	13	3	-	-

* Distance of tow generally between 3150 and 6300 m

The observations reported above provide a start in understanding reaction of fish to towed gear. Many important questions remain. What proportion of fish in the path of a trawl actually escape? What stimuli encourage orientation to the direction of tow? How do environmental factors such as depth, season, and temperature influence behaviour? More tank studies with the advantages of a controlled environment and the relative ease in repeating experiments are needed. Many more tows with the camera mounted in various parts of the trawl undoubtedly will enhance our knowledge. Improvements in sensitivity of underwater television to low levels of light may provide for continuous observations at normal towing depths without artificial lights.

5 REFERENCES

- Beamish, F.W.H., Swimming endurance of some Northwest Atlantic fishes. J.Fish.Res.
1966 Bd Can., 23(3):341-7
- Blaxter, J.H.S. and B.B. Parrish, The reaction of marine fish to moving netting and
1965 other devices in tanks. Mar.Res., 1966(1):15
- Blazka, P., M.Volf and M. Cepela, A new type of respirometer for the determination of
1960 the metabolism of fish in an active state. Physiologia bohemoslov.,
9:553-8
- Carrothers, P.J.G., Automatic underwater photographic equipment for fisheries
1967 research. Bull.Fish.Res.Bd Can., (159):34 p.
- Clark, J.R., R. Livingstone Jr., and J.M. Crossen, Development and operation of
1959 television for studying fish behaviour in otter trawls. Spec.scient.
Rep.U.S.Fish.Wildl.Serv., (320):21 p.
- Craig, R.E., and R. Priestly, Undersea photography in marine research. Mar.Res.,
1963 1963(1):24
- Welsby, V.G., J.H.S. Blaxter and C.J. Chapman, Electronically scanned sonar in the
1963 investigation of fish behaviour. Nature,Lond., 199(4897):980-1

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Acknowledgements

It is a pleasure to acknowledge the encouragement given by Drs. F.D. McCracken and J.L. Hart of the Fisheries Research Board of Canada at St. Andrews, New Brunswick. Technical advice generously given by Mr. P.J.G. Carrothers and the design of the camera housing was, of course, essential to the study. The assistance from Messrs. U. Buerkle, R. Chandler, and the crews of the M.V. Mallotus, M.V. Harengus, and C.G.S. A.T. Cameron is greatly appreciated.

PROBLEMS OF DESIGNING FISHING GEAR
AS RELATED TO BEHAVIOUR OF FISH

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Abstract

Several problems in gear design were considered. Gillnet thread materials, the spatial volume of trawl codends and the effects of leader nets were described in relation to both fish body contraction and the auditory senses of fish.

It was suggested that the most effective coloured lights for attracting fish were the shorter wave-length blue light (460 to 510 m μ) and orange light (570 to 620 m μ), and that the most effective frightening light appeared to be the brandishing of a light beam. Further, the visual axis of the fish eye and the sense for following flashing objects has to be considered in the design of longline fishing gear.

The design of an electro-fishing gear was determined from the results of electro-physiological and behavioural experiments.

Finally, from consideration of the physiological thermodynamics of the fish body, thermal stimulations resulting from the temperature of the surrounding water were described and considered to be a reasonable explanation of the shifting of "favourable fishing grounds".

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PROBLEMES QUE POSE LA CONCEPTION DES ENGINS DE PÊCHE EN FONCTION DU COMPORTEMENT DES POISSONS

Résumé

L'auteur étudie plusieurs problèmes soulevés par la conception des engins de pêche, et traite notamment des matériaux utilisés pour la confection des filets maillants, du volume de la poche des chaluts et de l'effet des filets-guides en fonction de la contraction du corps des poissons et du sens auditif de ces animaux.

L'auteur avance l'hypothèse que pour attirer le poisson, les lumières colorées les plus efficaces sont la lumière bleue de faible longueur d'onde (de 460 à 510 m) et la lumière orange (de 570 à 620 m μ), tandis que pour l'effrayer, l'agitation d'un faisceau de lumière, paraît le dispositif lumineux le plus efficace. En outre, dans le dessin des palangres, il faut tenir compte de la position de l'axe visuel de l'oeil du poisson et de sa sensibilité aux objets miroitants.

Un engin de pêche électrique a été conçu sur la base de résultats d'expériences portant sur l'électrophysiologie et le comportement du poisson.

Enfin, à partir de considérations sur la thermodynamique physiologique du corps du poisson, l'auteur décrit les stimulations thermiques exercées par la température de l'eau ambiante, qu'il juge fournir une explication raisonnable du déplacement des bons fonds de pêche.

PROBLEMAS DE LA CONSTRUCCION DE EQUIPO DE PESCA RELACIONADO CON EL COMPORTAMIENTO DE LOS PECES

Extracto

Se examinan diversos problemas planteados por la construcción de equipo de pesca. Los materiales de los hilos empleados en las redes de enmalle, el volumen del copo de los artes de arrastre y los efectos de las redes de las raberas se describen con relación a la contracción del cuerpo y el sentido del oído de los peces.

Se indica que los mejores colores para las luces que atraen peces son el azul de longitud de onda corta (460 a 510 m μ) y la luz naranja (570 a 620 m μ), y que lo más eficaz para ahuyentarlos consiste en mover violentamente una luz blanca. Al proyectar palangres se ha de tomar en consideración el eje visual del ojo del pez y su capacidad para seguir objetos que centellean.

El diseño de un equipo de electropesca se decidió a partir de los resultados de experimentos electrofisiológicos y de comportamiento.

Finalmente, del estudio de la termodinámica fisiológica del cuerpo del pez se describieron estímulos térmicos creados por la temperatura del agua que se consideraron como una explicación razonable de las variaciones de los bancos de pesca favorables.

1 INTRODUCTION

In this paper, some problems in designing various fishing gear related to fish behaviour are described. These problems are considered from the point of view of relations between fishing gear and individual fish. The problems are restricted to combinations of certain fishing gear and behaviour of fish as follows: gillnet materials and swimming power of fish, spatial volume of codend and spatial density of schools, vibration of lead-net and auditory sense of fish, electro-fishing gear and fish response to electric stimuli.

2 PROBLEMS RELATED TO FISH MOTION

2.1 Relation between the thread of gillnetting and the moving power of gilled fish

Let us consider the elongation of the thread length of a gillnet mesh and the contraction of the girth of an inserted fish body (Nashimoto, 1965). When the perimeter length of mesh is 1.00 the most probable girth length of the fish is about 1.15 for salmon (Konda, 1966).

If the elongation of the mesh in percent and the shortening of the girth length of the fish in percent (abscissa) are plotted against the contraction load of the mesh (ordinate) in regard to time elapsed the crossing points indicate the balancing condition at the respective time after the fish was inserted into the mesh (Fig. 1). Point B_0 represents the condition at time $t=0$, just after insertion of a fish into a net mesh, i.e. the mesh is elongated from 1.00 to about 1.04 and the girth of the fish is contracted from 1.15 to 1.04. The tensile force of thread T_0 is comparable to the body weight of the fish and varies with its activity.

With increasing time ($t=0, t_1, t_2, t_3, \dots, t_n$), the balancing condition point shifts from B_0 to $B_1, B_2, B_3, \dots, B_n$, and the retaining force becomes weaker and shifts from T_0 to $T_1, T_2, T_3, \dots, T_n$. When the retaining force decreases too much ($\ll T_n$), the net mesh becomes unable to hold the fish body. That is, the fish body falls out of the mesh. Consequently the setting period of a gillnet (from setting the net in the sea to hauling up) should be shorter than the time length (t_n) in which the retaining force of the net thread becomes too weak to hold fish body.

In consideration of the above phenomena, the selection of net thread materials and the choice of the meshsize of gillnet should be decided as follows:

(a) The mesh perimeter, elongated by the force of the fish, must be of a suitable length for insertion of the probable girth of the fish.

(b) The plastic elongation of the mesh perimeter, increasing with elapsed time, must not be too much. That is, the retaining force of the net must not become too weak to hold fish body before the net has been hauled up aboard.

In Fig.2 the characteristic curves of an ideal thread material for gillnetting are shown. For a certain meshsize of this thread, it is possible to catch fish in a wide range of body lengths ($G_1 - G_2$).

2.2 Relation between spatial volume of the codend of a trawl net and the spatial density of fish schools

We shall examine the problem of the minimum space in which fish are scarcely able to swim in the codend of a trawl net. When too many fish are in the codend during trawl fishing, fish bodies will clog the mesh of the net. In addition, the warp tension of the trawl net may be increased suddenly and fish bodies may be injured. Consider a narrow water path through which we make only one fish swim (Higo, 1967). In a certain current

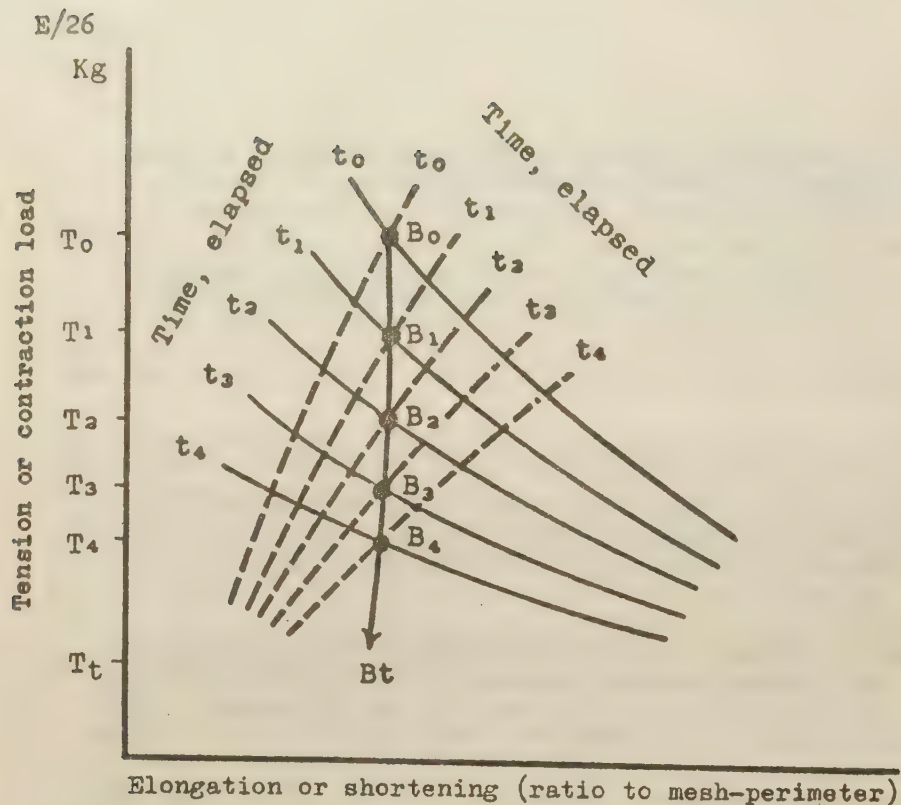


Fig. 1 Balancing conditions.

B_0, B_1, B_2, B_3 ---, B_t = balancing condition points after fish was inserted into a mesh at the intervals t_0 (initiation), t_1, t_2, t_3 , --- t_n of the time elapsed

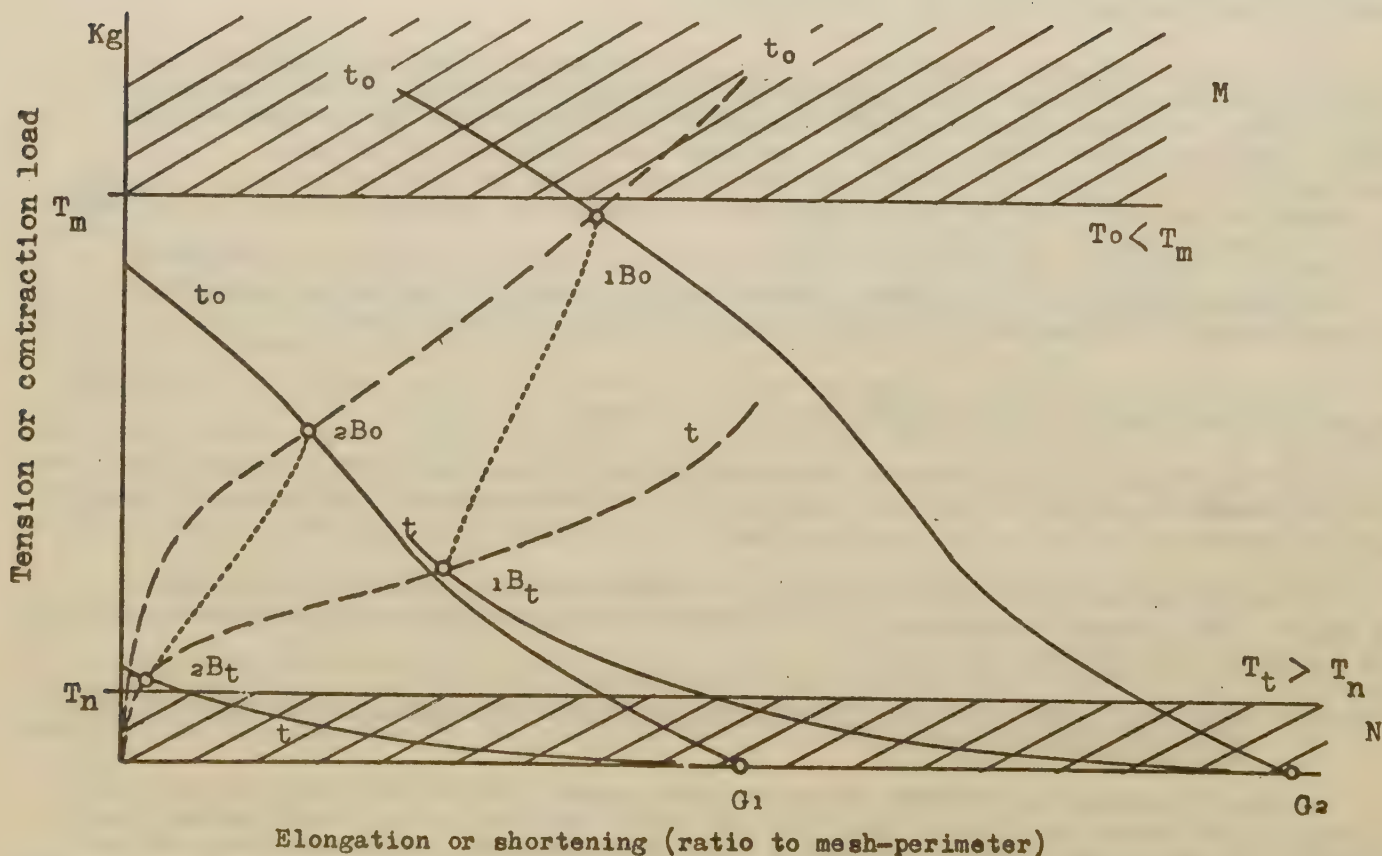


Fig. 2 Characteristic curves of an ideal thread material.

G_1 = girth length of a small fish body

G_2 = girth length of a large fish body

M (upper hatching zone) = too strong load to insert fish body

N (lower hatching zone) = too weak load to hold fish body for hauling up aboard

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velocity, the width of the path in which U-turn moving of fish is permitted completely has a relation " π -times" to the breadth of the fish body. We know, by way of other experiments that the radius of curvature of the artificially bent living fish body has a relationship with the breadth of the body.

We shall assume that fish can swim naturally in a codend only when they have sufficient space. This space is more than π^3 -times their own body volume. For example, according to this assumption, using (length) 15m x (breadth) 8m x (height) 3m of net, we may be able to catch approximately 5 tons of fish with this volume, 155m^3 of codend. ($\pi^3 \approx 31,155/31=5$).

2.3 Leader net and auditory sense of fish

Generally it is thought that the effects of leading fish by any fixed shore net are due to the avoidance of twines by visual sense of the fish. For example, even if the meshsize of the leader net is too large to be a barrier to swimming through it, schools of fish are led into the main trap of a fixed net. However, these observations have been reported frequently even on dark nights when the visual sense of fish may not be solely operative. The auditory sense may be involved on such dark nights. The main axis of directional detectability for a sound source by the auditory sense of a fish is slightly anterior to the midline of the body axis itself as shown in Fig.3. The auditory sense of fish in this direction of the detection axis is more sensitive to low frequency vibrations than high frequency ones (Kuroki, 1950, 1957).

On the other hand, it is known that ropes or twines in water current vibrate just as a whipped rod in air. When the diameter of rope is $d(\text{cm})$ and the current velocity is $V(\text{cm/sec})$, the frequency of vibration $n(\text{c/sec})$ in high tension rope is given by the following formula:

$$n=0.2 V/d$$

where 0.2 is "Strouhal's number" (see Fig.4). In low tension rope, Strouhal's number changes as shown in the following experimental formula: (Kuroki, 1958)

$$n=0.12 V/d$$

For example, when a current ($V=100 \text{ cm/sec}$) presses the leader net (of which the twine diameter $d=0.3\text{cm}$), the twine of the net may be vibrated in a frequency of 66c/sec .

$$n = \frac{0.2 \times 100}{0.3} = 66$$

If fish swim up to the leader net under this condition, the vibration should be detected by the auditory sense of fish in the direction of its axis of movement. Then, the fish may swim, avoiding the net, to deeper and deeper water; i.e. the fish is led offshore, at last to the main trap of the fixed net.

3 PROBLEMS OF VISUAL SENSE AND FISHING GEAR

3.1 Colour of the light of attracting fish lamp

For the purpose of investigating the relations between coloured light intensities and aggregated fish, tests and observations were carried out. Hundred watt in-put underwater fluorescent colour lamps (7 colours, i.e. white green, daylight white, cobalt, blue, pink, yellow and red) were used experimentally at 8 points on Kagoshima Bay, Japan, 1957-58 (Kuroki, et.al. 1964). The distributions of coloured light intensities were measured with a sensitive photometer which contained 5 kinds of colour filters (V, B, G, Y and R).

Fish schools aggregated to lamps were investigated simultaneously by two echosounders, one of them on a moving skiff and the other one on an anchored ship. Furthermore, sea water temperature, salinity and vitamin B₁₂ were measured. Under the attracting conditions, fish caught by net or hooks were young mackerel (Pneumatophorus japonicus, Houttyn; body length 12-15cm): (Engraulis japonica, Trachurus japonicus and others).

From the results of the investigation we may say that (a) the shapes of fish school aggregated to the lamp resemble large bowls, but they are very variable. These fish are very lively and sensitive (see Fig. 5): (b) the limit of the nearest distance of fish schools from the lamp seems to be obtained by orange light (570-620m μ); on the other hand the farthest range from the lamp seems to be controlled by blue light (460-510m μ).

It may be concluded that the most effective kinds of coloured light for attracting fish are firstly white-green and cobalt, and secondly blue and daylight white. In any case, it may be stated that orange light must not be too intense and blue light must not be too weak.

3.2 Frightening light for fish

It is interesting to note that, in spite of the existence of the attracting effectiveness of light for fish, there is a fright reaction to light for the same fish under certain light conditions.

From the results of experiments in our laboratory (Kuroki, et al. 1953) it was found that the following light types were ineffective in driving fish schools: (i) lighting on or off or blinking of light; (ii) steady light beam or blinking light through a slit and (iii) light beam reflected from a mirror on the tank bottom (i.e. to light up the ventral side of fish body). It was found that only brandishing of the light beam across the water path was very effective even in water with appreciable current (See Table I).

TABLE I - Comparison of the relative values of swimming frequency across a brandished light beam

Motor	Conditions		Sweeping velocity of light beam (m/sec)		
	Light	Current	1-1.3	5-6	22-
X	X	X	100	100	100
O	X	X	90	87	87
O	O	X	81*	50**	55**
O	X	O	84	85	85
O	O	O	57**	54**	67*

X : stopping*statistically significant at 95% level of confidence

O : running**statistically significant at 99% level of confidence

It may be stated that fish are frightened by a light beam (or source) when it is shifting across ahead of the fish in the water with a higher velocity than the swimming speed of fish. We found, however, that a strong flashing light (about 100 lumen, 2 x 10⁻⁵sec. Xe-tube 150Kg/cm²) had a slight effect in disturbing a swimming shoal of fish (mackerel) in the sea, but the effective period was very short, lasting only 3 min (see Fig. 6).

In order to utilize light to prevent fish from swimming out of a purse seine when its ends are going to connect to each other, a new type moving (high speed) light source must be devised for the unconnected space of the purse seine near the termination of its pursing operation.

3.3 Branch lines of longline fishing

It is a well known fact that an effective hooking of fish happens more frequently in the centre branch line of every main (one unit) line than the other (end-side) branch lines (Table II), (Morita, 1964, 1966). It used to be thought that the distribution of hooking rates might be based on the deeper swimming layer of fish schools. However, this fact is explained by the visual sense of fish.

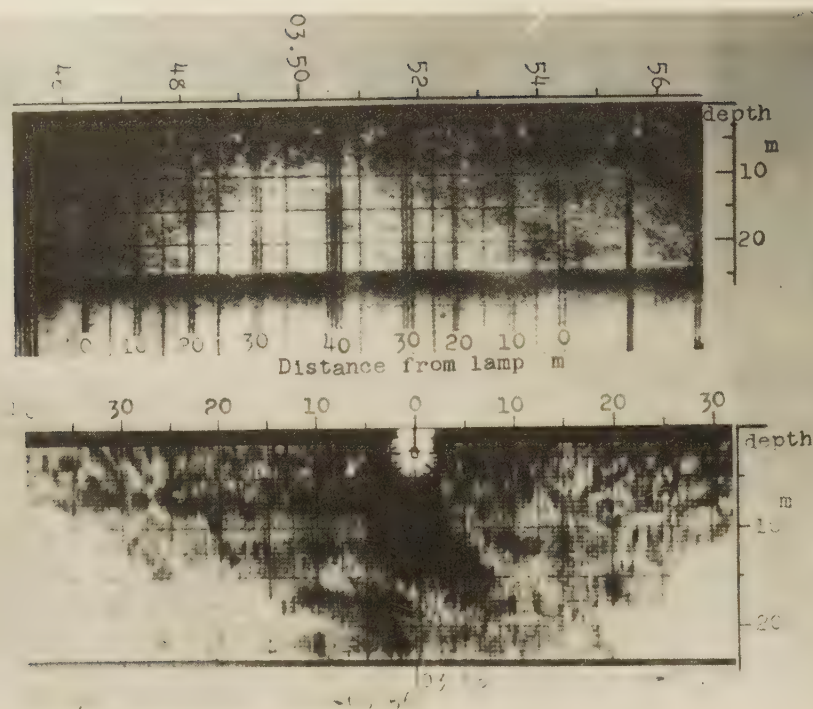


Fig.5 Echosounder recordings showing the shape of a fish school aggregated under white-green light (11 November, 1958).

Above: traces recorded from a skiff

Below: Echogram re-arranged to show the shape of the fish school

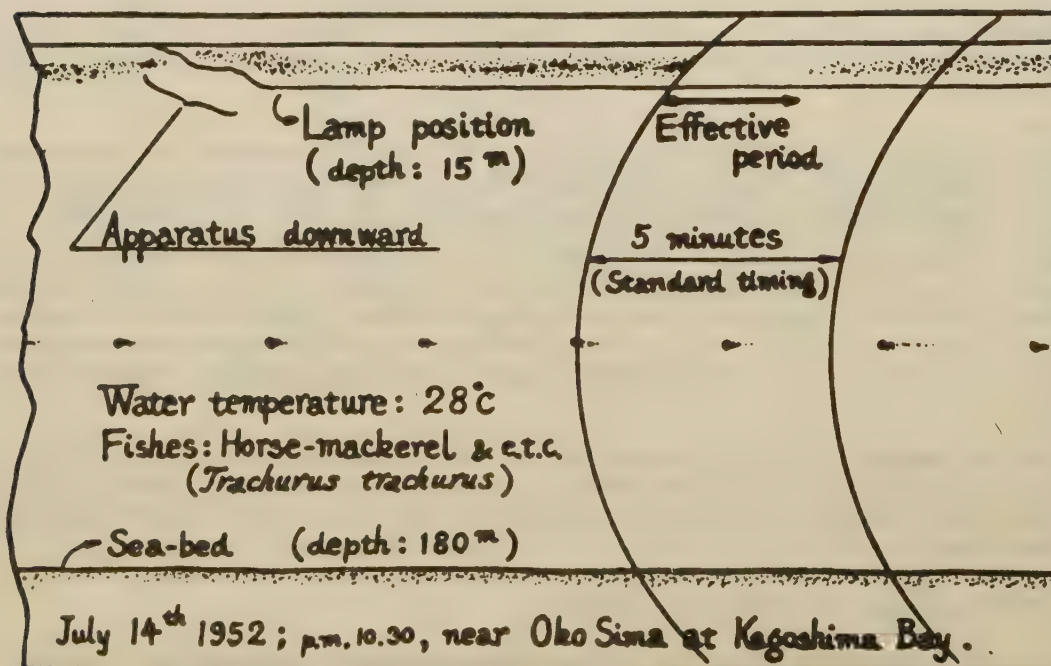


Fig.6 An example of the effect of a strong flashing light (14 July, 1952, 22.30 hours, off the shores of Oko Is. in Kagoshima Bay)

Lamp: 5000 Volt Xe-tube ($150\text{kg}/\text{cm}^2$), 10^6 lumen, 2×10^{-5} sec.
Fish: Mackerel (body length ca. 15cm) and others.

TABLE II - Catches by 50 baskets with 4-hooks or 5-hooks per one unit main line (consisting of one basket)

Date Feb. 1956	4-hooks gear					5-hooks gear					
	hook position					hook position					
	(1)	(2)	(3)	(4)	total	(1)	(2)	(3)	(4)	(5)	total
3	2	7	6	1	16	2	4	8	6	3	23
4	4	6	5	5	20	3	2	4	2	2	13
5	5	3	5	1	10	2	2	2	2	1	9
6	1	6	5	3	19	1	3	5	7	2	18
7	3	1	4	4	12	2	1	11	4	4	22
8	3	12	6	2	23	1	10	9	5	3	28
10	3	5	5	1	14	0	6	4	1	3	14
11	3	6	8	5	22	1	3	4	8	1	17
12	5	6	5	1	17	1	3	4	6	3	17
13	4	9	7	2	22	1	5	6	5	2	19
14	4	7	8	3	22	2	8	4	7	4	25
15	4	5	2	1	12	2	2	4	4	0	12
Total	41	73	66	29	209	18	49	67	55	28	217

Fish (especially tuna) have their visual axis in a direction slightly above and ahead of the body. When they see ropes (main line and branch line) in their visual space, they will swim to deeper and deeper water because their body axis inclines in slightly lower direction (Nakamura, 1964). Thus, fish may be led to the deepest bait of the center branch line.

During bait seeking, fish may find the center branch line more frequently than the other (end-sides) branch lines. When the visual range of fish is comparable to the distances between two branch lines, the probability of finding the branch lines may be about a half that of finding the center branch line.

In the new design of longline fishing gear, the distance between one end branch in a main line and the neighbouring end branch in the main line must be considered in relation to the visual acuity of fish. (Nakamura, 1964).

3.4 Visual sense of fish for flashing objects

It is said that the highest fishing rate in tuna longlining or the most effective catch in skipjack fishing is achieved by using live bait.

We tried to use several kinds of artificial bait in longline fishing, which were very similar to living saury in shape and colour from the human visual sense but were made of nylon material. Even when the artificial baits were dipped in a squid-oil or mixed bait, the hooking rate in the longline fishing was extremely poor.

It seems, in tuna and skipjack fishing that the visual sense of fish is more important than the sense of smell or taste. And, the most important sense of fish must be the visual one for flashing objects because living baits must gleam in their swimming state.

According to the report in which the visual sense of fish for flashing objects was investigated (Tamura, et al. 1959) the critical fusion frequencies of various kinds of fish were 10-50c/sec. These values may be comparable to live-baits gleaming.

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4 PROBLEMS OF ELECTRO-FISHING

4.1 Consideration of the minimum value of electric power needed

Generally, strong electrolytes are dissolved in sea water. The most serious point in designing electro-fishing gear is to decide the minimum electric power needed. Concerning electric stimuli, Weiss' hyperbola is well known in the relation between the strength of stimuli and the stimulus duration (Fig. 7) (Kuroki, 1955).

We know, through an elementary mathematical consideration, that the minimum electric power may be gained at a stimulus duration of b/a in Fig. 7; the duration equals "Chronaxie".

Three Chronaxies must be considered respectively for three purposes, i.e. instantaneous electrocuting, severe electrifying and restorable electrifying.

For the purpose of instantaneous electrocuting (for example, to kill shark) it is necessary to use the highest voltage or the strongest electric current and the shortest duration (10^{-4} to 10^{-3} sec) of stimulus. On the other hand, for the purpose of restorable electrifying (for example, to guide fish by electric fence), it is required to use the lowest voltage and the longest duration (10^{-2} to 10^{-3} sec) (See Fig. 8) (Kuroki, 1953).

Actual voltage to be used must be decided in accordance with the kinds of fish, the body length of fish, the distance between two electrodes, etc.

4.2 ζ -point and rhythm of stimulation

When a fish is stimulated in the space between two electrodes, the fish swims ahead or turns back in accordance with the position of the electrodes. That is, when the electrodes are behind the fish, the fish are driven ahead by electric stimuli, and when the electrodes are set at front, the fish turn back (Kuroki, 1950). Of course, in these experiments the electrodes must be hidden in waterweed for the purpose of deadening visual sense effects.

A point is designated as the " ζ -point", at which the swimming motion (forward or reverse) is decided according to the position (rear or front side) of the electrodes. It was described in one report (Suzuki, et al. 1953) that the " ζ -point" coincided with the position of fish labyrinth.

In the event that a slight electrifying effect is utilized for guiding fish, the electric stimulus should be given to the fish before the ζ -point has been in the effective zone of electrifying. Then, the rhythm f_1 of stimuli is given the formula as follows:

$$f_1 \geq v/l$$

where V is swimming velocity, l is the length from snout to ζ -point (10-13 percent of body length) (See Fig. 9).

In the other case where severe electrocuting is desired, even one stimulus must not be given before the ζ -point (or full body of fish) has been in the effective zone. Then, the rhythm f_2 of strong stimuli is given by the following formula:

$$v/(d_2+1) > f_2 \geq v/(d_1-1)$$

where d_1 is the width of strong electrocuting zone, d_2 is the one of the weak electrifying zone, respectively around the electrodes (See Fig. 10). Obviously, it is required that $d_1 > d_2$; but this condition may not be obtained generally by a simple arrangement of one row electrodes (especially by direct current or monophasic alternative current).

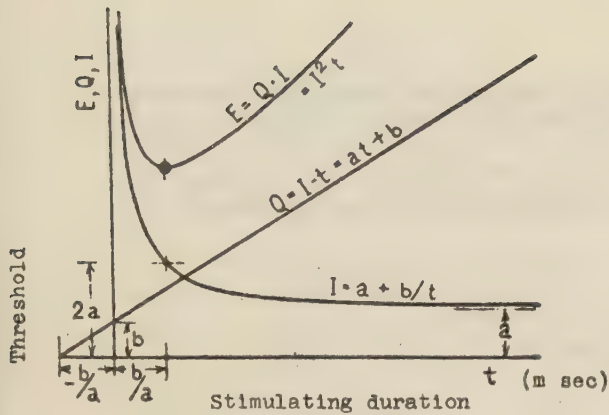


Fig. 7 WEISS' hyperbola for electric stimuli.

I = current; V = voltage; Q = quantity of electricity;
 E = electric energy
 a = rheobase; b/a = chronaxie
 $I = a + b/t$; $Q = I \cdot t = at + b$; $E = Q \cdot I = I^2 \cdot t$
 at E (minimum), $t = b/a$ (chronaxie) and $I = 2a$

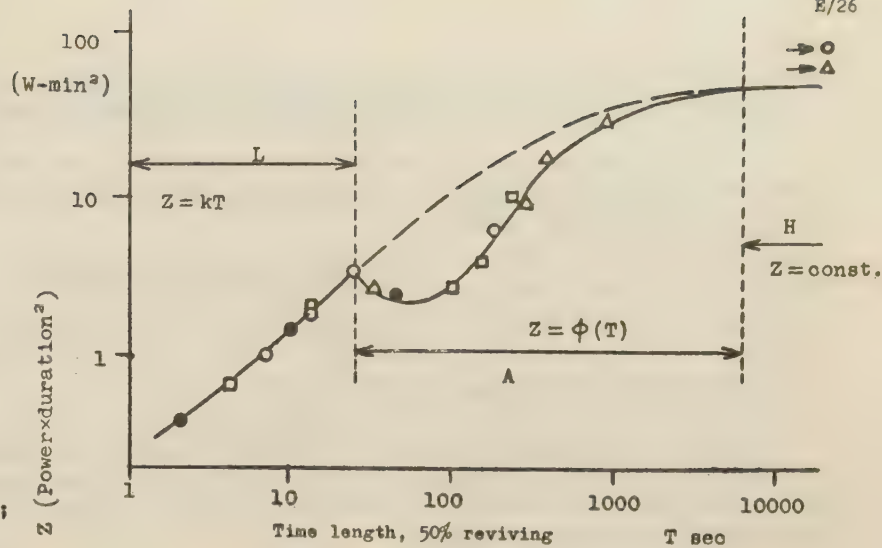
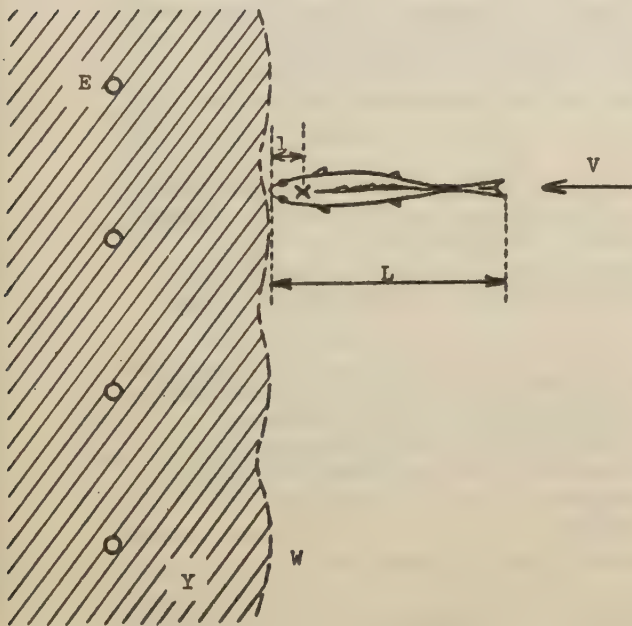
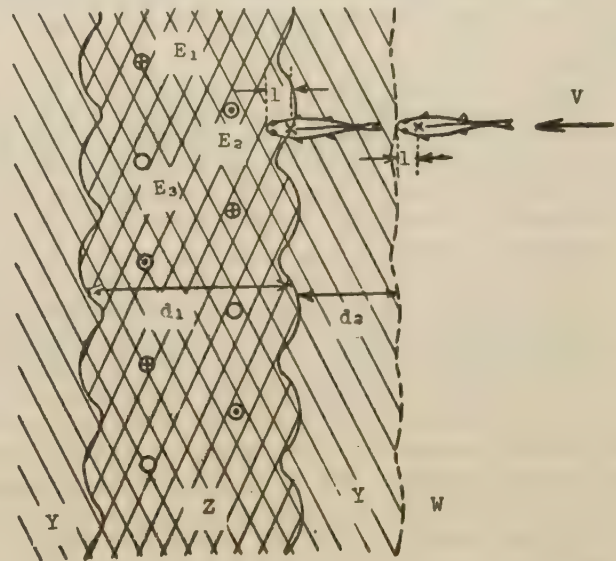


Fig. 8 Reviving characteristic curve of fish from electrifying.

L = proportional zone (linear function); A = abnormal zone (complex function);
 H = horizontal zone (constant value to death)

Fig. 9 Explanation of electrifying rhythm (f_1) to guide fish.

E = electrodes; V = swimming velocity (cm/sec);
 L = body length of fish (cm); l = distance length
 between snout and ξ -point (cm); $l = (0.1 \sim 0.13)L$;
 Y = electrifying zone; W = invalid zone
 $f_1 \geq V/l$

Fig. 10 Explanation of electrocuting rhythm (f_2) to kill fish.

E = electrodes (Δ -arrangement of 3-phase elect.);
 V = swimming velocity (cm/sec); l = distance length
 between snout and ξ -point (cm); $l = (0.1 \sim 0.13)L$;
 Y = electrifying zone; W = invalid zone;
 Z = electrocuting zone; d_1 = width of Z-zone;
 d_2 = width of Y-zone; $V/(d_2 + l) \cdot f_2 = V/(d_1 - l)$

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To attain the condition $d_1 > d_2$ the special arrangement of electrodes must be considered, for example, three phases of Δ (delta) arrangement (see Fig.10) (Kuroki, 1953).

Actual values of f_1 and f_2 are calculated for brook trout (body length 50cm, $l=6$ cm, $V=40$ cm/sec) and shark (body length 200cm, $l=26$ cm, $V=200$ cm/sec, $d_1=500$ cm, $d_2=300$ cm) respectively as follows:

(brook trout): $f_1 > 70/\text{sec}$

(shark): $0.6\text{c/s} > f_2 > 0.40/\text{sec}$

5 PROBLEMS OF THERMAL STIMULATION

The fish senses (auditory, visual, taste) are recognized as similar to the senses of mammals and birds. However, at least for "temperature", the sense of fish should be different from the mammal or bird because the former is a poikilothermal animal and the latter are homoiothermal.

There are some problems to be considered about the "temperature" stimulation on fish.

First, in the adaption condition (i.e. when a certain degree of "temperature" is holding on for a long period of time), the temperature difference between fish body (poikilothermal body) and the environmental water may become smaller and smaller with time elapsed; on the other hand, the temperature differences between homoiothermal animals and their environmental air or water may be staying at a certain value for the period.

Second, even under the adaption condition, there are often the facts that the temperature of fish body is not always equal to the environmental temperature. When the physiological state of fish body adapted in a certain temperature may be assumed "endothermal", the body temperature will be lower than the water temperature and, reversely, the body temperature will be higher than the water temperature under the exothermal state.

Third, these physiological (exothermal, endothermal and not either) states may alternate successively within a certain period, i.e. there may be a biorhythmic cycle (Sollberger, 1965). Then, according to the physiological state and growing stage and season, the temperature difference between the fish body and the surrounding water may be measured differently even in the same species of fish. But, the physiological states of fish must be stable during a short period in which there is not any periodical change; we call the stable thermal states "static adaption".

In this chapter, let us treat the thermal stimulation on fish under the static adaption.

5.1 Fundamental experiments of the "temperature" variations

It is generally said that the receptors of fish for the change of the water temperature may be laid on the lateral line system (Dijkgraaf, 1966): but when the time duration of temperature changing will be comparable to the duration of the thermal transmission in a fish body, we must consider that the thermal stimulations for fish may be received not only by the receptors on the lateral lines but by many systems of various sensory organs on the fish body.

Although it may be permitted to consider that the thermal stimulation on a homoiothermal animal will be effected only by "temperature" (in $^{\circ}\text{C}$ or in $^{\circ}\text{F}$) itself, we have to consider that the thermal stimulation on fish (poikilothermal animal) in its static adaption will be effected not by "temperature" itself but by "temperature change".

To investigate the above the temperature in the abdomen of swimming fish was measured (Fig.11) while the temperature of the surrounding water was varied abruptly, or other stimuli applied.

In these experiments some interesting phenomena were observed as follows:

- (a) Rainbow trout: body temperature decreased about 0.15°C by lighting (in a dark room). It also decreased about 0.30°C suddenly by the sound of footsteps at midnight. In both cases the temperature decreases were recovered after about 20 min (at $15-18^{\circ}\text{C}$ water temperature).
- (b) Goldfish: body temperature increased suddenly $0.2-0.25^{\circ}\text{C}$ by stimuli of light or sound, and then recovered gradually. It took $4\frac{1}{2}$ hours to recover. Usually the fluctuation of body temperature under steady (normal) conditions had a periodicity of about 110 min (increasing 70 min and decreasing 40 min).
- (c) The following tendencies of body temperature to the environmental water temperature were exponential in nature. It was presumed that the physiological condition in goldfish may be exothermal and that the one in rainbow trout may be endothermal.
- (d) Increasing of body temperature occurred just after operations, perhaps due to struggling motions. The tendencies of recovery were not exponential.

From these results and observations we know that fish may be very sensitive to temperature change in a certain period and may not be so sensitive in another period. The relation between the behaviour of fish and the temperature circumstances may be variable and very complex, because the internal physiological conditions may be variable with time and space in the ocean and with the fish life history stage.

5.2 Theoretical consideration

The exponential lines along which the body temperature is going to follow the changed water temperature are shown typically in Fig. 12. When t is the time elapsed and it is measured from the beginning of the temperature change of fish body, we obtain the temperature difference (θ) between the fish body and the surrounding water by the Eq. (1) as follows:

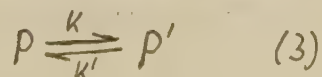
$$\theta = \theta_0 e^{-ct} \quad (1)$$

where θ_0 is the maximum value of the temperature difference of the water in its abrupt change (at $t=0$), c is a constant but its value depends on the position at where the body temperature is measured.

From Eq.(1), we obtain the Eq.(2)

$$\frac{d\theta}{dt} = -c \cdot \theta \quad (2)$$

Here let us assume a reversible system in the sensitive organ as follows:



This system may be either a chemical reaction or some physical process such as a change in the spatial distribution of some substance. k and k' in the equation are the rate constants of the processes indicated by the arrows. The concentrations of P and P' at the equilibrium which may be denoted by $[P]$, $[P']$ respectively are given by:

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Fig.11 Swimming goldfish (♂) with two thermistors. One thermistor was inserted into his abdomen and the other was carried on just outside of the body (Fish body length about 19cm).

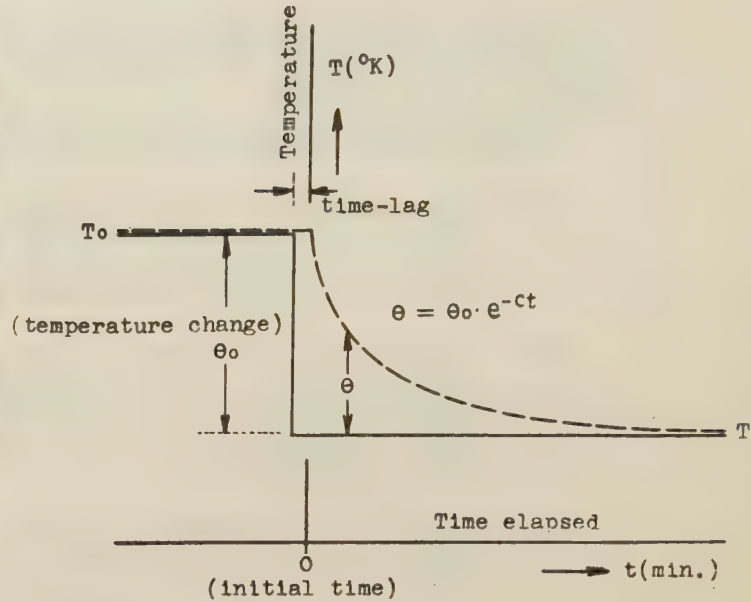


Fig.12 Typical illustration of the adaption of the body temperature to the surrounding water temperature.

Full line = water temperature; Broken line = body temperature. T = temperature ($^{\circ}\text{K}$); θ_0 = maximum value of the temperature difference; θ = temperature difference at t

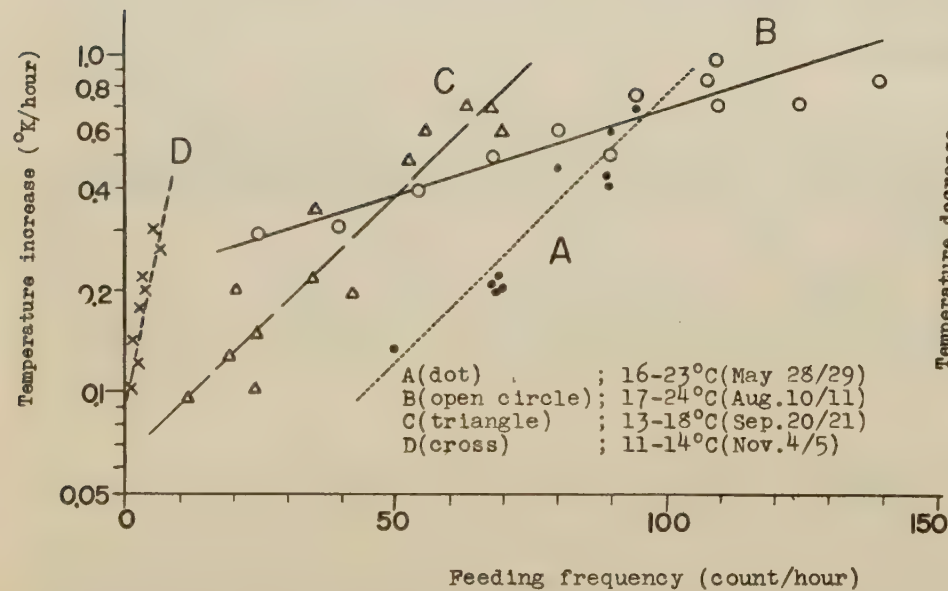


Fig.13 Linear relation between the temperature increase (in log.scale) and the feeding frequency of goldfish.
(By Kuroki after Hirata [1960])

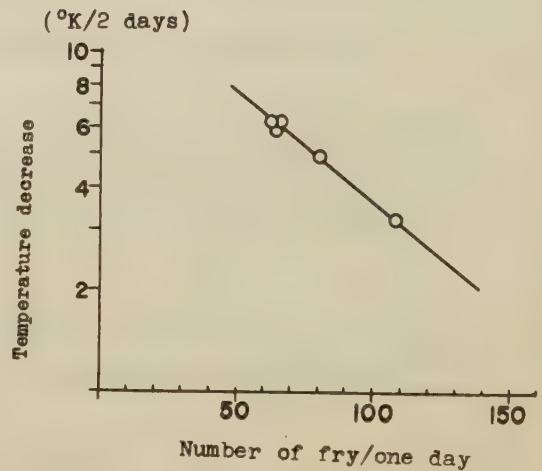


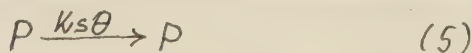
Fig. 14 Relation between the temperature decrease in 2 days and the upstream movement of rainbow trout (August 3-8, 1954; at Loon outlet creek)

(By Kuroki after Northcoote [1962]).

$$[P] = \frac{k' \bar{L}}{k + k'}, \quad [P'] = \frac{k \bar{L}}{k + k'} \quad (4)$$

where $\bar{L} = [P] + [P']$, which is supposed to be constant.

When the system receives a stimulus of a temperature change θ , the following reaction occurs presumably with a rate constant proportional to θ . (k_s ; constant)



When superposing on the equilibrium (the Eq.3), the stimulus of θ is applied to the system, the concentration of P will increase with the following velocity:

$$\frac{d[P']}{dt} = (k_s \theta + k)(\bar{L} - [P']) - k'[P'] \quad (6)$$

From this and the Eq.(2), we obtain

$$\begin{aligned} \frac{d[P']}{dt} &= \frac{d[P']}{d\theta} \cdot \frac{d\theta}{dt} = \frac{d[P']}{d\theta} \cdot (-c \cdot \theta) \\ \text{or} \quad \frac{d[P']}{d\theta} &= \frac{(k_s \theta + k)(\bar{L} - [P']) - k'[P']}{-c \cdot \theta} \quad (7) \end{aligned}$$

Now let us consider about a certain parameter E . This parameter may be called "Sensation". Generally, its change dE shall be related to the "free energy" F in the following manner (Tamiya, 1952):

$$\frac{dE}{dF} = \alpha \quad (\alpha = \text{constant}) \quad (8)$$

And the relation between the free energy F and the concentration $[P']$ is given by the "Second Law of Thermodynamics" as follows:

$$\frac{dF}{d[P']} = \frac{RT}{[P']} \quad (9)$$

where R is the Gas Constant and T is the absolute temperature (in $^{\circ}K$). From the Eqs. (8) and (9),

$$\frac{dE}{d\theta} = \frac{\alpha RT}{[P']} \cdot \frac{d[P']}{d\theta} \quad (10)$$

$$\text{c.f.} \quad \frac{dE}{d\theta} = \frac{dE}{dF} \cdot \frac{dF}{d[P']} \cdot \frac{d[P']}{d\theta}$$

Substituting the Eq.(7) into the Eq.(10),

$$\frac{dE}{d\theta} = \frac{\alpha RT}{[P']} \cdot \frac{(k_s \theta + k)(\bar{L} - [P']) - k'[P']}{-c \cdot \theta} \quad (11)$$

From this, consider the relation

$$\bar{L} = [P] + [P'],$$

$$\frac{dE}{d\theta} = \frac{\alpha RT}{c \cdot \theta} \left\{ k' - (k_s \theta + k) \frac{[P]}{[P']} \right\} \quad (12)$$

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for simplifying, put $\{K' - (K_s\theta + K) \cdot [P]/[P']\} \equiv \{W\}$

From the Eq.(12), we obtain

$$\frac{d\theta}{\theta} = \frac{dE \cdot c}{dRT} \cdot \frac{1}{\{W\}} \quad (13)$$

Transforming into finite form, we obtain the WEBER's Ratio as follows:

$$\frac{\Delta\theta}{\theta} = \Delta E \cdot \frac{c}{dRT\{W\}} \quad (14)$$

Integrating the Eq.(13), (c.f. $T \gg \theta$ and T may be considered as a constant for the change of θ),

$$\ln \cdot \theta = E \cdot \frac{c}{dRT\{W\}} \quad (15)$$

When T and $\{W\}$ are constants, the Eq.(15) shows the WEBER-FECHNER's Law.

It may be permitted to consider that when the value of the WEBER's Ratio $(\Delta\theta/\theta)$ is small, the organ must be sensible. In this consideration, we are able to interpret the Eq.(14) as follows:

- (a) When the value of c is smaller (i.e. the exponential slope is the more gentle), the organ is the more sensible.
- (b) When T ($^{\circ}\text{K}$) is higher, the organ is the more sensible.
- (c) When $\{W\}$ has a negative value, the organ is sensible for the temperature decreasing and, reversely, the organ is sensible for the temperature increasing at the positive value of $\{W\}$. And, when the value of W becomes smaller and smaller (i.e. $\Delta\theta/\theta$ becomes larger), the organ becomes insensible against the change of the surrounding temperature.

5.3 Interpretation of some experimental results about the thermal stimulation on fish

The results of the experiments which were carried out by Hirata (1960) about the feeding behaviour of goldfish showed that the feeding frequency is correlated with the temperature change (θ) rather than the temperature itself (T)

When the parameter E (sensation) in the Eq.(15) may be assumed as the feeding frequency, it must have a linear relation with the logarithmic value of θ from this equation. This was confirmed by experiments which were conducted in different temperature ranges (in various seasons). Accordingly $\{W\} > 0$, and the value of $\{W\}$ may be larger in higher temperature and smaller in lower temperature. Especially in November, the value of $\{W\}$ is very small, that is, WEBER's Ratio becomes very high in the Eq.(14). In other words, the fish become insensible to the temperature change in this season at least as regards the feeding behaviour.

For another example, the result of calculation regarding the temperature changes is shown in Fig.14.

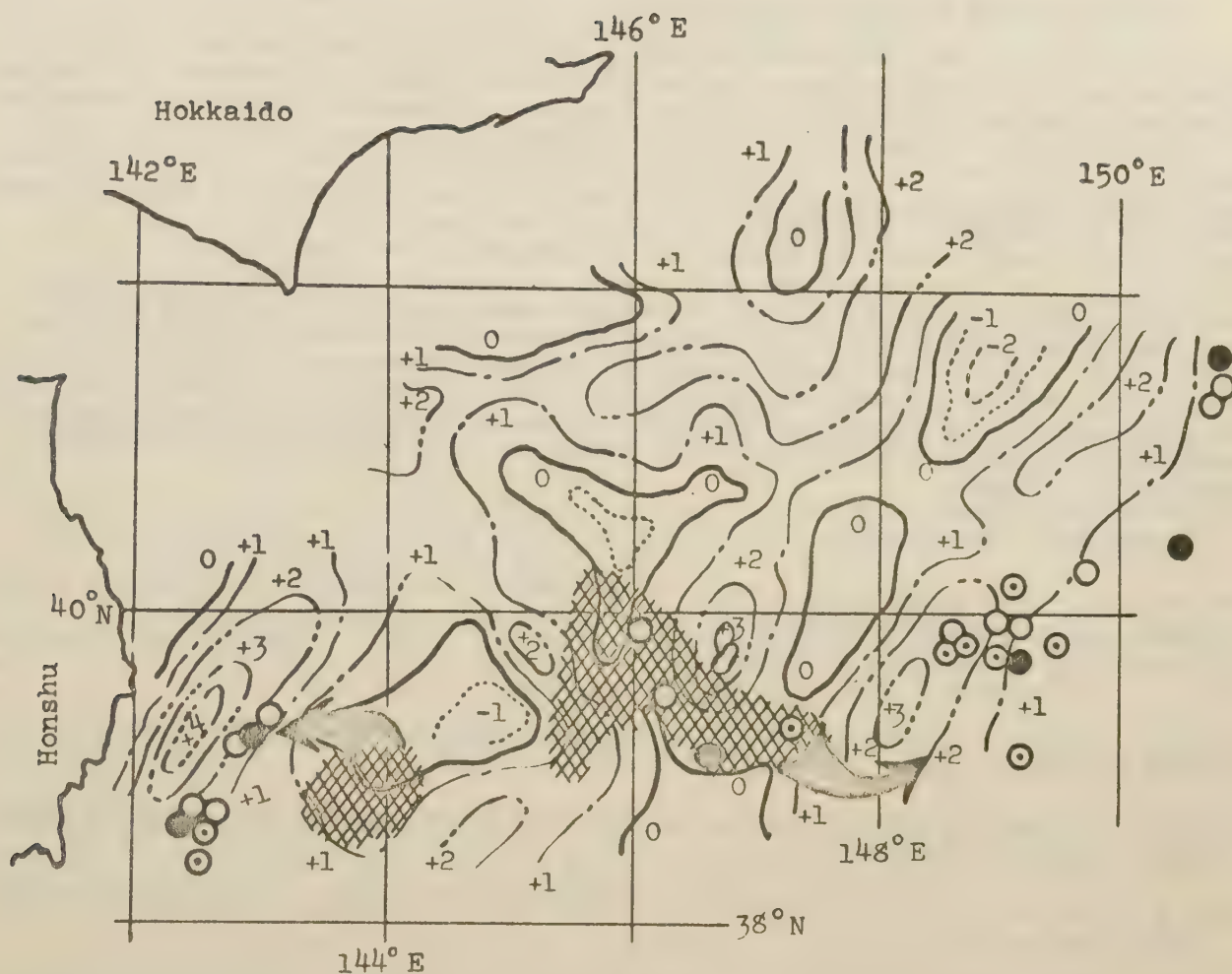


Fig.15 Iso-differential thermolines and the shifting of "favourable fishing" points, between 26-31 July and 1-5 August.

Hatching zone = good fishing ground for the last period; Open circle = 3 ton or less of catch; Circle dot = 3-10 ton of catch; Solid circle = 10 ton or more of catch.

Northcote (1962) described precisely the migratory behaviour of juvenile rainbow trout. When the parameter E is shown as the number of rainbow trout moving upstream (per one day), the temperature change (θ), the logarithmic value of which must have a linear relation with E , can be calculated from Eq.(15). In this case it was found out that the value of θ is not the temperature decrease "per one day" but the accumulative decrease "for successive two days" (See the ordinate in Fig.14).

In spite of the reverse appearance about the inclinations of the lines in Fig.13 and Fig. 14, the signs of $\{W\}$ are positive in both cases. It may be presumed that $\{W\} > 0$ is generally true in the sense of fish for the temperature stimulus.

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5.4 Application in the fishing ground

Up to this time the predictive evaluation of fishing grounds has been conducted mainly through the relations between actual catches and water temperatures. That is, the sea water temperatures have been thought as the most important factor in determining fishing grounds. Now it is suggested that not only temperatures themselves but temperature differences in time and space in the ocean in relation to "fishing ground" must be considered. For example, the shifting locations of "favourable fishing areas" of skipjack are explained more reasonably through the distribution of the iso-differential thermal lines than through the iso-thermal lines (see Fig. 15).

A more precise expression of the iso-differential thermal lines may be obtained theoretically, not with T itself but with $\Delta T/T$, where ΔT is the temperature difference at one point at two successive times (for example, yesterday and today, the last week and this week, etc.) where T is the absolute temperature of sea water at the point. However, the range of T is about 273° - 300° K in the ocean. Therefore, permitting 1-3 percent error, we may use the value of ΔT instead of $\Delta T/T$ to draw iso-differential thermolines on a chart.

6 REFERENCES

- Dijkgraaf, S., Biological significance of the lateral line organs. In Lateral line
1966 detectors; proceedings of a Conference held at Yeshiva University,
New York, April 16-18, 1966, edited by P.J. Cahn. Bloomington, Indiana
University Press
- Higo, N., Spatial -times effects in swimming motions of fish. 1. Annual Meeting
1967 Japanese Society Scientific Fisheries, Tokyo
- Hirata, H., Diurnal rhythm of the feeding activity of goldfish. Bull.Japan.Soc.scient.
1960 Fish., 26(8):783-91
- Konda, M., Studies on the optimum mesh of salmon gillnet. Mem.Fac.Fish.Hokkaido Univ.,
1966 14(1-2):1-88
- Kuroki, T., Biophysical studies on the auditory characteristic of fish. Mem.Fac.Fish.
1950 Kagoshima Univ., 8:89-100
- _____, Study on the electric fish screen. 1. Bull.Japan.Soc.scient.Fish.,
1950 16(4):165-70
- _____, Study on the electric fish screen. 4. Bull.Japan.Soc.scient.Fish.,
1952 18(1):25-9
- _____, Study on the electric fish screen. 9. Bull.Japan.Soc.scient.Fish.,
1953 18(12):698-702
- _____, Study on the electric fish screen. Bull.Japan.Soc.scient.Fish.,
1953 18(9):385-88
- _____, Electrical fishing. Tokyo, M.Onuma, Giho-do, 190 p.
1955
- _____, Biophysical studies on the auditory characteristic of fish. 1. Direction
1957 audibility through one lateral line. Bull.Japan.Soc.scient.Fish., 23(7-8):
400-4
- _____, Fundamental studies on the relation between underwater sound and fish
1958 behaviour. 2. About the sound by ropes in water. Mem.Fac.Fish.Kagoshima
Univ., 6:89-94

- Kuroki, T., N. Nakayama and K. Ueno, Studies on the fluorescent colour lamp for
1964 attracting of fish. 2. Bull.Fac.Fish.Hokkaido Univ., 14(4):215-35
- Kuroki, T., K. Nashimoto and T. Fujii, The fluctuations of sea water temperature
1965 observed continually during one day at two points on the ocean one mile
apart. Bull.Fac.Fish.Hokkaido Univ., 15(4):243-59
- _____, Thermal stimulation on fish. Bull.Japan.Soc.scient.Fish., 33(3):264-74
1967
- _____, Theoretical analysis of the role of the lateral line in directional
1967 hearing. In Lateral line detectors; proceedings of a Conference held at
Yeshiva University, New York, April 16-18, 1966, edited by P.H. Cahn.
Bloomington, Indiana University Press
- _____, et al., Shunning light for fisheries. Bull.Japan.Soc.scient.Fish.,
1953 18(10):468-71
- Morita, T., Experimental studies on the feeding reaction of fishes to each hook in
1964 the small longline gear. 1. On the results of experiments by 5 - hook gear.
Mem.Fac.Fish.Kagoshima Univ., 13:110-4
- _____, Experimental studies on the feeding reaction of fishes to each hook in
1966 the small longline gear. 2. On the results of experiments by the various
construction gears. Mem.Fac.Fish.Kagoshima Univ., 15:83-90
- Nakamura, E., A method of measuring visual acuity of scombrids. Proc.Hawaii.Acad.Sci.,
1964 39:26-7
- Nashimoto, K., Fundamental studies on the phenomena of sticks in gillnetting. 1.
1965 Theoretical consideration and experimental analysis of sticking phenomena
in mesh. Bull.Fac.Fish.Hokkaido Univ., 15(4):221-33
- _____, Fundamental studies on the phenomena of sticks in gillnetting. 2.
1966 The measuring method of the time elapsed after sticking in mesh and the
problem of its utilization. Bull.Fac.Fish.Hokkaido Univ., 17(1):33-46
- Northcote, T.G., Migratory behaviour of juvenile rainbow trout in outlet and inlet
1962 stream of Loon Lake, B.C. J.Fish.Res.Bd Can., 19(2):201-70
- Sollberger, A., Biological rhythm research. New York, Elsevier Pub.Co., 461 p.
1965
- Suzuki, M. et al., Electric stimuli on fish body. Kagaku, 23(7):367-8
1953
- Tamura, T., A study of visual perception in fish. Bull.Japan.Soc.scient.Fish.,
1957 22(9):536-57
- _____, et al., The flicker electroretinogram of the carp eye. Bull.Japan.Soc.
scient.Fish., 25:624-31
1959
- Yamamoto, S. and S. Mishima, Study on the suitable mesh size for salmon gillnet.
1962. Bull.Fac.Fish.Hokkaido Univ., 13(2):82-97

THE BEHAVIOUR OF THE NORWEGIAN TRIBE OF
THE ATLANTO-SCANDIAN HERRING

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Abstract

The herring stocks that contribute to the winter fishery in the Norwegian coastal waters migrate to the polar front in summer and concentrate in a restricted area east of Iceland, returning in late December or early January to their spawning grounds on the Norwegian coastal banks, their course and speed of movement governed by the optimum surface water temperature of 6° to 8°C, moving at depths of 200 to 300 m during the day and close to the surface at night.

The location and depth of the spawning area is also determined by this optimum temperature range.

The schools of spent fish leave the coastal banks by late March and again concentrate along the polar front in June, and the cycle is repeated.

COMPORTEMENT DU GROUPE NORVEGIEN
DE HARENGS ATLANTICO-SCANDINAVES

Résumé

Les stocks de harengs qui alimentent la pêche d'hiver dans les eaux côtières norvégiennes gagnent le front polaire en été et se concentrent dans un secteur restreint à l'est de l'Islande, pour retourner vers la fin de décembre ou le début de janvier à leurs frayères des bancs côtiers norvégiens. Leur itinéraire et leur vitesse de déplacement sont commandés par la température optimale de l'eau de surface, qui est de 6° à 8°C. Ils nagent à 200-300 mètres de profondeur le jour et près de la surface durant la nuit.

L'emplacement et la profondeur des frayères sont également déterminés par la gamme optimale de températures indiquée ci-dessus.

Les harengs guais quittent les bancs côtiers fin mars au plus tard pour se rassembler de nouveau le long du front polaire en juin, et le cycle se répète.

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EL COMPORTAMIENTO DE LA SECCION NORUEGA DEL ARENQUE
ATLANTICO-ESCANIDNAVO

Extracto

Las poblaciones de arenque que se pescan en el invierno en aguas costeras noruegas, emigran hacia el frente polar en el verano y se concentran en una zona muy pequeña al este de Islandia. A fines de diciembre o principios de enero regresan a sus zonas de desove en los bancos costeros noruegos siendo gobernados su dirección y velocidad por la temperatura óptima de la superficie del agua, de 6° a 8°C, hundiéndose a profundidades de 200 a 300 metros durante el día y aproximándose a la superficie durante la noche.

Esta gama de temperatura es óptima y determina el lugar y profundidad de la zona de desove.

Los cardúmenes de arenque que ha desovado se alejan de los bancos costeros a fines de marzo y vuelven a congregarse a lo largo del frente polar en junio, para repetir el ciclo.

1 INTRODUCTION

Norway is well endowed by nature for fishing, as two of perhaps the most important species of commercial fishes in Europe—the Arcto-Norwegian cod and the Atlanto-Scandian herring—invade the Norwegian coast each year for spawning. As a result, Norway has developed important coastal and seasonal fisheries. This paper deals only with the herring, mainly with the mature part of the stock.

2 THE NORWEGIAN HERRING FISHERIES

The Norwegian herring fishery exploits three groups of herring; the small herring, the fat herring and the winter herring.

2.1 The small herring fisheries

Herring belonging to the 0-group and the I-group are found all along the Norwegian coast. During the century a fairly intensive fishery has developed, based on these small herring, together with the development of a canning industry and the building of reduction plants for oil and meal. The fishery is carried out by specially constructed purse seines, and the main catch is obtained in western and northern Norway.

2.2 The fat herring fisheries

The herring which are still immature and at an age of 2 to 5 years are called fat herring in Norway. These age-groups are usually available in Northern Norway and have for centuries been the basis of very important fisheries. Previously the fat herring were caught by using beach seines and tangle nets, but in this century the purse seine has become the most important gear. In recent years, the main bulk of fat herring have been caught in the area off eastern Finmark.

2.3 The winter herring fisheries

The most important Norwegian herring fishery has been the so-called winter herring fishery. This is based upon schools of herring invading the coastal waters of Norway for spawning. The fishery can be traced back, in Norwegian history, to more than a thousand years. The herring schools were followed by schools of whales and thousands of birds. The fishermen, therefore, had no difficulty in locating the herring when they arrived.

The gear used for catching the herring were beach seines and tangle nets. Drift-nets were brought into use in 1896 in the Norwegian winter herring fisheries and from the beginning of this century the purse seine has been used to net a steadily increasing part of the catch. In recent years ships equipped with sonar, powerblock and ringnets are responsible for the main part of the Norwegian herring catch.

3 THE BEHAVIOUR OF THE NORWEGIAN WINTER HERRING

For centuries it has been known that the Norwegian winter herring invaded the Norwegian coastal waters for spawning, disappearing again after a couple of months. No one knew from whence it came and where it went. Several theories attempting to explain this behaviour pattern have been printed through the centuries, but these are not reviewed in this short paper. It was the Icelandic herring expert Arni Fridriksson who first observed that the important summer herring fisheries off north Iceland and the Norwegian winter herring fisheries were based mainly upon the same stock of herring (Fridriksson, 1935; 1944).

In spite of Fridriksson's convincing paper (Fridriksson, 1944) one important point evaded understanding. Fridriksson showed that in Icelandic waters the maximum yield of herring was obtained when they were 11 to 12 years old; but Einar Lea (Lea, 1930) found that in the Norwegian winter herring fishery the maximum yield of a yearclass was ob-

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tained when the herring were only 6 to 7 years old. Another problem arose after Fridriksson's paper had been printed. During the years immediately following the second world war, the Norwegian winter herring catches increased year by year, while at the same time the herring off northern Iceland disappeared.

The only conclusion that could be drawn from these two points was that the main part of the Norwegian winter herring did not show up in the area fished off northern Iceland. The vital questions remaining unanswered were:

- (a) In what areas could the main part of the Norwegian winter herring stock be found during the summer?
- (b) Could herring be found during summer in big enough concentrations to support an economic fishery?

3.1 The behaviour of the Norwegian winter herring during the summer

In 1950 Fiskeridirektorates Havforskningsinstitutt began operating R/V G.O. SARS which was equipped with echo-sounders and ASDIC and therefore was able to locate pelagic fish schools at least within a mile from the ship. R/V G.O. SARS was, in 1950, the only ship connected with fishery research which was equipped for the task of locating herring schools in the open sea. Helland-Hansen and Nansen (1909) had presented a map showing the distribution of Calanidae in the southern Norwegian Sea. It was also a well known fact that different species of Calanidae (especially Calanus finmarchicus) form the main food of herring and so the areas where the herring were most likely to be found were clear.

During the summer of 1950 R/V G.O. SARS went out in the Norwegian Sea looking for the herring. As a result of this cruise it was concluded that in the summer of 1950 there were plenty of herring feeding along the polar front on the eastern, southern and western sides of the East Icelandic Current, and northwards to the Jan Mayen area. The main concentrations of herring were located in surface temperatures from 6° to 8°C. In the Jan Mayen area they were found in lower temperatures as well.

The herring were located mainly in the warmer surface waters above the pronounced thermocline, which in the summer were found in the border regions of the East Icelandic Arctic Current. Smaller schools of herring could be found in the surface water when the depth down to the thermocline was only a few meters; but larger schools suitable for purse-seining were usually found where the depth of the thermocline was greater. The latter condition was found to prevail further to the east when the ship was operating on the eastern side of the cold water, and likewise, further south and west when fishing on the southern or western side of the East Icelandic Arctic Current. It appeared that some area of warm water was needed for the formation of larger schools. These summer schooling conditions are now a well known fact. Later investigations show that concentrations of herring schools are found also along the polar front between Jan Mayen and Bear Island.

3.2 The behaviour in autumn and early winter

After the cruise of R/V G.O. SARS during the summer of 1950 we knew where we should look for the Norwegian winter herring in the summer. The question where they could be found in late autumn and early winter is answered in a Soviet paper by Glebov (1938). Glebov studied the behaviour of the small herring off the Murmansk coast and reached two very important conclusions:

- (a) During the summer, invasions of herring into the fjords occur in the years when the temperatures in the fjords are higher than in the area outside the fjord;
- (b) During the winter, invasions of herring take place when the temperatures are lower in the fjords than in the adjacent water outside.

Glebov (1938) offered plausible explanations of these two observations. During the short summer there is plenty of food for the herring and they feed in waters of high temperatures where the metabolism is rapid. During the winter there is a scarcity of food and the herring accumulate in waters of lower temperature where the rate of metabolism is lowered. If the behaviour of the mature herring in the Norwegian sea also followed Glebov's laws, the area in which they would most likely be found would be in the arctic waters of the East Icelandic Current.

Early in December 1950 we again went out in the Norwegian Sea with G.O. SARS in order to test this hypothesis. A few sections were taken across the East Icelandic Current and dense schools of herring were located in the arctic water mainly on the western side of the current with surface temperatures of 2 to 3°C, fairly close to the front of the Atlantic water further west.

Later research in Norway supported by Soviet and Icelandic investigations showed that during late September and October the herring accumulate in a comparatively small area in the arctic water to the east of Iceland. They remain in this area until late December or early January. During the day the herring schools may be located down to 500 m depth, but in the evening they approach the surface and stay more or less dispersed in the surface layer during the night and dive down again in the morning. A large fleet of drifters from U.S.S.R. has been fishing herring in this area for the last 15 years with success. Great stern trawlers with pelagic trawls are also used. In the last two seasons Icelandic ringnet boats and trawlers from the Federal Republic of Germany have also taken part in the herring fisheries of this area.

3.3 The spawning migration

During late December or early January the herring schools begin to move towards their spawning areas, and during 1950 to 1951 we succeeded in tracing this migration to the Norwegian coastal banks. Since that year a Norwegian research vessel has, every winter, followed the herring schools from their wintering area east of Iceland to the Norwegian coast. The herring are also followed by a great fleet of drifters and stern trawlers from U.S.S.R.; in recent years also by purse seiners from the Faroe Islands and by trawlers from the Federal Republic of Germany.

The herring follow the front between the Arctic water of the East Icelandic Arctic Current and the Atlantic water on its western and southern side, as far as possible, in the direction of the Norwegian coast. The schools keep mainly to a temperature of 6°C to 7°C, but can pass through areas with temperatures of up to 9°C when moving through the Atlantic water off the Norwegian coastal banks.

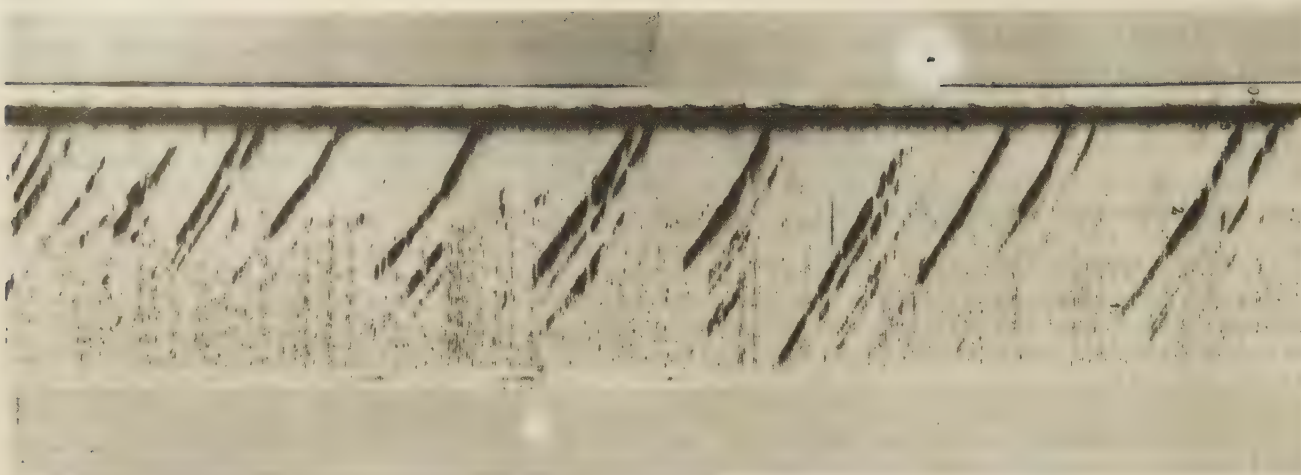
The schools are very dense and extensive, and the herring keep the formation of these dense schools day and night. In earlier years, when R/V G.O. SARS was the only ship that followed the schools, they kept close to the surface during the night but in the day they moved eastwards at a depth of 200 to 300 m. Now, when followed by a fleet of fishing vessels, the schools are mainly found below 100 m depth even at night.

The speed of the schools is dependent upon the temperatures of the water they are passing through. In most westerly areas the speed is between 6 to 10 mi in 24 h, but when they pass through the Atlantic water off the Norwegian banks the speed is about 24 mi in 24 h and even up to 40 mi in 24 h.

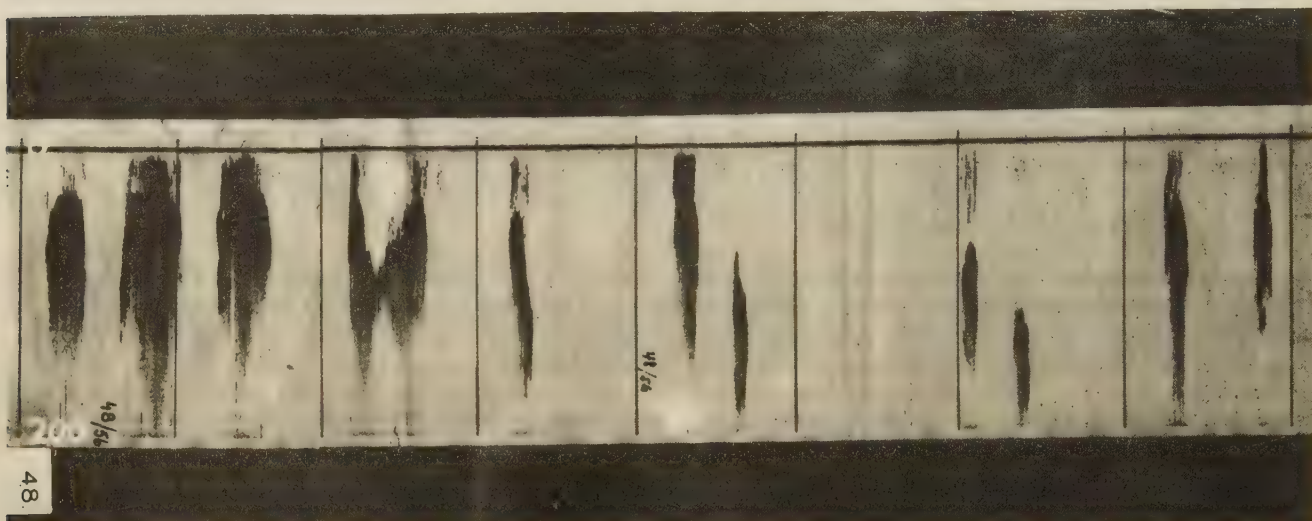
3.4 The behaviour in the spawning area

When the herring schools have reached the edge of the Norwegian coastal banks, some of them disperse but most remain as dense schools until they have arrived in the proper spawning area, after which they disperse during the first night. The next morning they again concentrate, but in smaller numbers than in the migrating schools. The next evening the schools are again dispersed and a new schooling takes place as soon as the light comes in the morning.

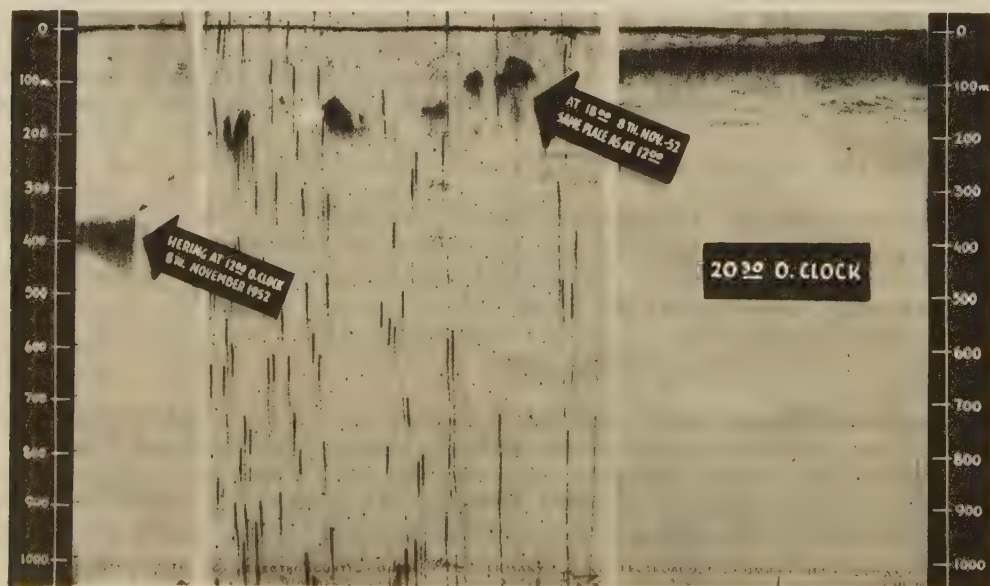
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Contacts of herring schools with Asdic when passing across the spawning migration route



Herring schools during spawning migration. Vertical scale 200 m, horizontal scale 1 mi between vertical lines. The schools approaching the surface can be seen from the echos from the gas above.



Herring school's behaviour in the wintering area. The school is kept within reach of G.O.Sars' Asdic for about 9 hours

This behaviour continues for some days, and the herring start inspecting the bottom during the day, and the spawning takes place during the day close to the bottom. Spawning usually occurs about 30 days after the arrival of the herring in the spawning area. If the herring are late in reaching the spawning area, it appears that less than 30 days are necessary before spawning takes place.

At the location of spawning, the water temperature varies mainly from 6 to 8°C. The herring appear to avoid water of less than 5°C at the surface, even when the temperature at the bottom may be 6 to 8°C. In the years when the coastal Norwegian surface water is above 5°C, spawning takes place close to the shore in 30 to 60 m depth. In cold years spawning takes place further off the coast and in deeper water (200 m or more) where the temperature during the spawning period is higher.

Spawning in shallow water is quite apparent because the billions of sperms make the sea visibly milky. The fishermen then abandon the area, because the herring would soon be leaving. The spent schools can be followed in late March to the edge of the coastal banks, but the paths they follow during April and early May are still unknown. In June they again accumulate along the polar front and the cycle is repeated.

4 REFERENCES

- Fridriksson, A., Staerd Norsku og islensku sildarinnar. Ægir, 1935:159-60
1935
- _____, The herring off the north coast of Iceland. Rit Fiskideildan, (1):340 p.
1944
- Glebov, T.I., Coastal migration of the Murmansk herring associated with ecological
1938 factors. Trudy poliar.nauchno-issled.Inst.morsk.ryb.Khoz.Okeanogr.,
(1):5-58
- Helland-Hansen, B. and F. Nansen, The Norwegian Sea. Its physical oceanography based
1909 based upon Norwegian research 1900-4. Rep.Norw.Fishery mar.Invest., 2(1)
- Lea, E., Mortality in the tribe of Norwegian herring. Rep.P.-v.Réun.Cons.perm.int.
1930 Explor.Mer, 65:100-17

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PÊCHE AVEC LAMPES IMMERGEES PRATIQUEE DANS
LE GOLFE SAINT-LAURENT

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Résumé

Ces essais ont été effectués du 16 août au 29 octobre 1966 au Québec, à l'entrée de la baie des Chaleurs et dans les eaux environnant les Iles-de-la-Madeleine, grâce à la collaboration de trois senneurs québécois.

Le matériel de pêche au feu a été installé successivement à bord d'embarcations porte-feu de 4 et 8 m remorquées par le senneur, puis à bord d'un bateau de 12 m se déplaçant de façon autonome. L'installation utilisée pour cette pêche est inspirée d'un système français. Elle consiste en une source lumineuse composée de deux baladeuses avec ampoules de 500 W à fond argenté et d'un platier portant cinq de ces ampoules. Les baladeuses et le platier sont étanches et peuvent être immergés, selon les besoins, jusqu'à 50 m. Le tout est alimenté sous une tension de 28/32 V, afin d'assurer le maximum de sécurité aux lampistes. L'électricité est produite par un groupe électrogène diesel de 5000 W, 120 V, c.a., 60 hertz, monophasé. Un rhéostat permet d'obtenir des variations continues de l'intensité lumineuse. Vingt-trois essais ont été réalisés avec ce matériel; les meilleures prises ont été de 25 à 40 tonnes de hareng. Plusieurs d'entre eux furent effectuées à la suite de détections faibles et éparses. Les résultats sont prometteurs puisque la période d'immersion des lampes a rarement dépassé deux heures.

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FISHING WITH SUBMERGED LAMPS AS PRACTISED IN THE GULF OF ST. LAURENT

Abstract

These experiments were carried out in 1966 from August 16 to October 29 in Québec at the entrance to the Bay of Chaleurs and in waters off the Magdalen Islands. They were made with the cooperation of three Québec seiners.

The equipment for light fishing were first installed on skiffs of 4 and 8 m towed by the seiner and then on a self-powered 12-m boat. The lighting system is of French origin. It includes a light source of two lamps with silvered 500-W bulbs and a reflector holding 5 identical bulbs. The lamps and the reflector are waterproof and may be lowered to a depth of 50 m. The light source is fed by a 5000-W, single phase, 120-V, 60-cycle, diesel-electric generator. Transformers convert the current to 28/32 V, thus providing maximum security to the operating personnel. The use of a rheostat permitted continuous variation of voltage.

Twenty-three experiments were made with this system and the best catches of herring ranged from 25 to 40 t, some being undertaken in spite of poor and scattered detection. The results are promising since the periods of immersion have rarely lasted more than two hours.

PESCA PRACTICADA EN EL GOLFO DE SAINT-LAURENT CON LAMPARAS SUMERGIDAS

Extracto

Estos experimentos se realizaron en 1966, desde el 16 de agosto al 29 de octubre, en Quebec, a la entrada de la Bahía de Chaleurs y en aguas fronterizas a las Islas Magdalena. Se llevaron a cabo con la cooperación de tres barcos cerqueros de Quebec.

El equipo necesario para la pesca con luz se instaló primero en pequeños botes de 4 y 8 metros remolcados por el cerquero y posteriormente en una embarcación motorizada de 12 metros. El sistema de alumbrado es de origen francés; está formado por una fuente luminosa de dos lámparas con bombillas plateadas de 500 vatios y un reflector que contiene 5 bombillas idénticas. Las lámparas y el reflector son impermeables y pueden bajarse hasta una profundidad de 50 metros. La fuente luminosa se halla alimentada por un generador diesel-eléctrico de 5.000 W, monofásico, de 120 V, y 60 ciclos. Los transformadores bajan el voltaje a 28/32 V, dando de este modo la máxima seguridad al personal operador. El empleo de un reostato permitió una variación continua del voltaje.

Se hicieron veintitrés experimentos con este sistema y las mejores capturas de arenque oscilaron entre 25 y 40 toneladas, llevándose a cabo algunos de tales experimentos a pesar de que la detección era mala y dispersa. Los resultados son prometedores ya que los períodos de inmersión raramente duraron más de dos horas.

1 INTRODUCTION

Les pêcheurs du Québec, profitant de l'amélioration que les techniques modernes ont apporté à un procédé ancien, pratiqueront bientôt la pêche au feu. Les eaux du golfe Saint-Laurent s'apparentent à celles de l'est de l'Atlantique et de la Mer du Nord; elles sont moins limpides que celles des zones tropicales et sub-tropicales, et il est nécessaire d'avoir un éclairage suffisamment puissant. Nous utilisons le courant électrique pour produire la source lumineuse afin d'obtenir une lumière très blanche, éblouissante et régulière, conditions essentielles pour attirer le poisson.

2 MATERIEL DE PÊCHE AU FEU

2.1 Lamps de pêche

La source lumineuse se compose de deux baladeuses avec ampoules de 500 W à fond argenté et d'un platier portant cinq ampoules de 500 W (Fig. 1). L'ensemble est étanche et alimenté sous tension de 24 V, afin d'assurer le maximum de sécurité aux lampistes. Les baladeuses et le platier peuvent être immergés, selon les besoins, jusqu'à 50 m, garantissant ainsi la luminosité nécessaire dans les eaux troubles et profondes. Pour des profondeurs relativement grandes, les douilles sont emplies d'huile qui garantit l'étanchéité de l'ensemble. Les lampes du platier sont alimentées indépendamment par un fil à deux conducteurs de 10 millimètres² de section. La mise au point d'un dispositif qui conserve la douille de l'ampoule à l'abri de l'eau tandis que la partie sphérique est au contact direct de l'eau, fut réalisée par l'Institut scientifique et technique des Pêches maritimes de France.

En général, le système français s'est révélé efficace, bien que nous ayons eu à déplorer quelques difficultés.

Pour pallier ces difficultés, nous avons demandé à une compagnie québécoise de nous fournir un modèle amélioré, construit de façon à prévenir les fuites d'huile le long des conducteurs et à simplifier le changement d'ampoule (Fig. 2, 3 et 4).

Ce nouveau projecteur est immergeable jusqu'à 50 m; les raccordements du câble d'alimentation se font dans la partie supérieure de la douille dans une chambre étanche et sans huile. Le remplissage d'huile de la partie inférieure de la douille s'effectue par un bouchon en bronze placé sur le côté de la douille. L'étanchéité est assurée par un joint en "téflon" et le serrage du bouchon se fait à la main. Le changement d'ampoule peut être effectué très facilement, car il suffit d'enlever l'ampoule grillée, de placer le joint d'étanchéité du col de la lampe sur la nouvelle ampoule et de la visser dans la douille. Il y a aussi d'autres avantages: a) la douille possède un crochet de support pour la suspension de la baladeuse, ce qui élimine toute traction sur le câble d'alimentation; b) elle est enduite d'un revêtement d'époxy pur qui résiste à la corrosion; c) le câble d'alimentation est en néoprène et non en caoutchouc naturel.

2.2 Groupe électrogène et "porte-feu"

Cette source lumineuse est alimentée par un groupe électrogène diesel de 5000 W, 120 V en c.a., 60 hertz, monophasé. Il est couplé à une unité indépendante de transformation et de contrôle, afin d'obtenir une tension 28/32 V (Fig. 5). Un autotransformateur variable nous permet de modifier l'intensité lumineuse d'une façon continue, dans un rapport de 4 à 1, nous offrant ainsi un champ expérimental très étendu. Toutes les sorties, allant du générateur au transformateur et du transformateur aux lampes, sont étanches.

Cet ensemble nous a donné satisfaction au cours de nos premiers essais. Les difficultés rencontrées nous amènent cependant à faire la remarque suivante: il serait probablement recommandable pour le pêcheur d'utiliser un groupe électrogène donnant directement du 32 V, afin de bénéficier de la simplicité, de la robustesse et de la sécurité qui en découleraient.

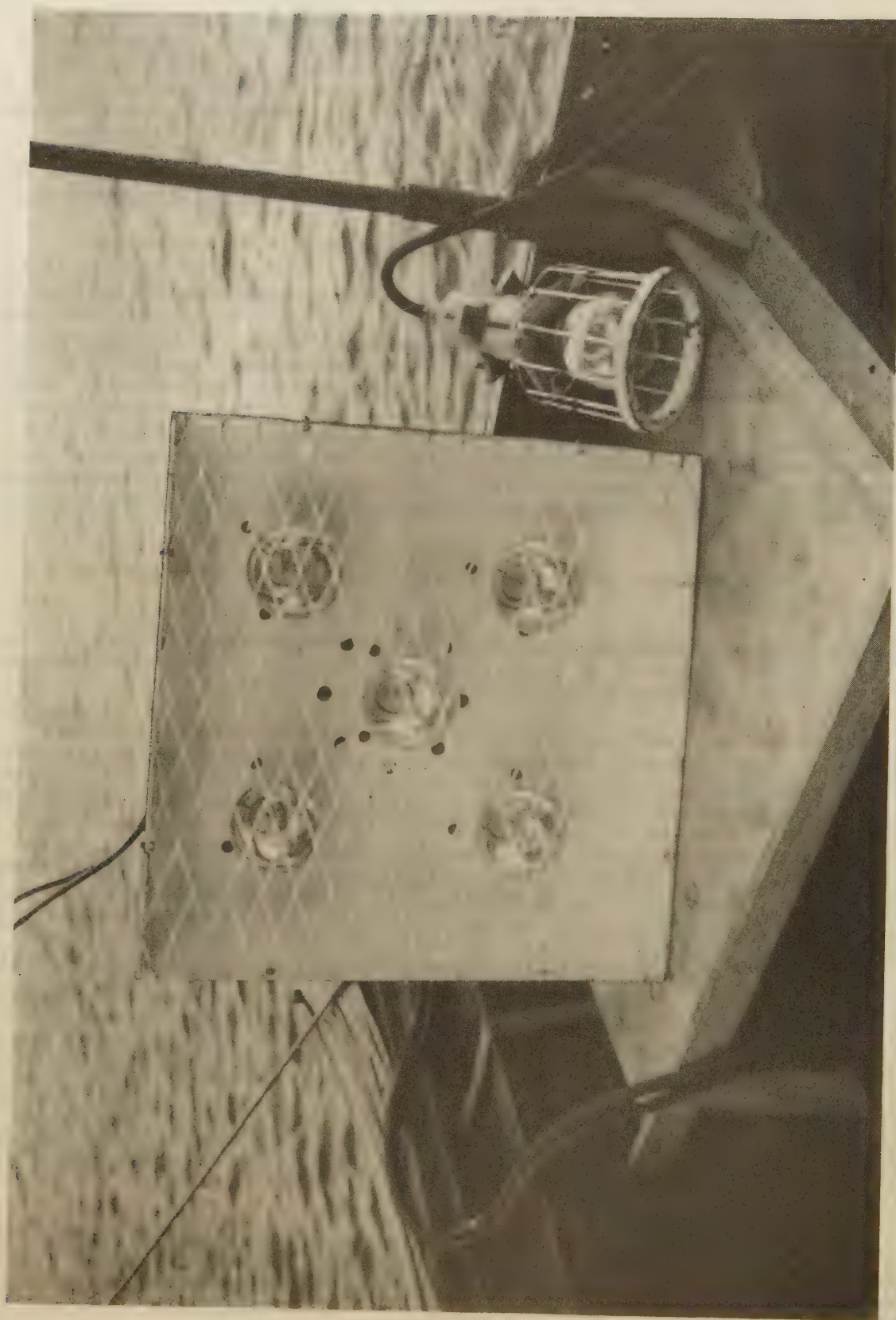


Fig. 1 Plâtier portant cinq ampoules de 500 watts à fond argenté et protégé par un grillage. A côté du plâtier, une des deux baladeuses

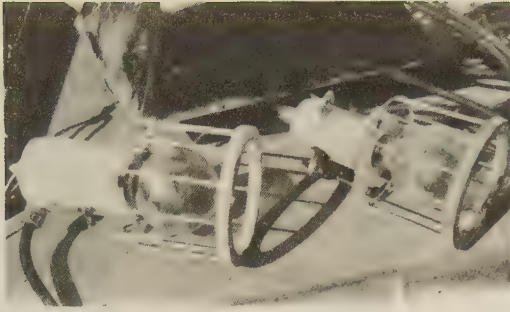


Fig. 2. Baladeuse (à droite) de fabrication française utilisée durant 430 heures, et baladeuse de fabrication canadienne (à gauche) utilisée durant 335 heures. / Lamp (right) of French manufacture used for 430 h, and one of Canadian fabrication (left) used for 335 h/.

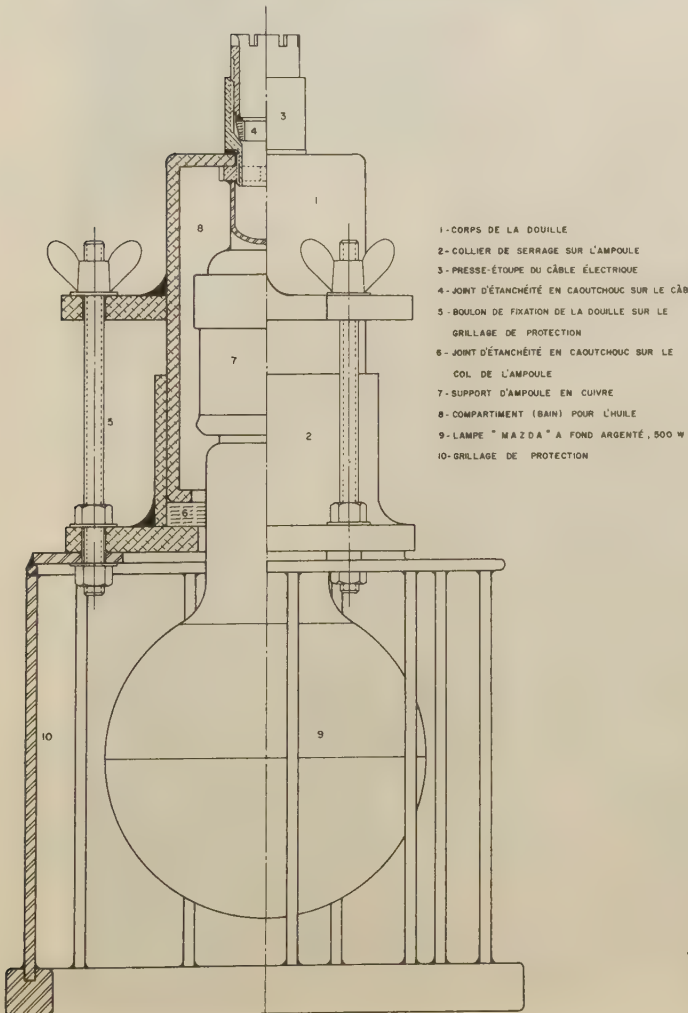


Fig. 3. Lampe de pêche immergeable du type "I.S.T.P.M."; fabrication française "Laudren". / Drawing of a submerged lamp of the type I.S.T.P.M., manufactured in France by Laudren, /

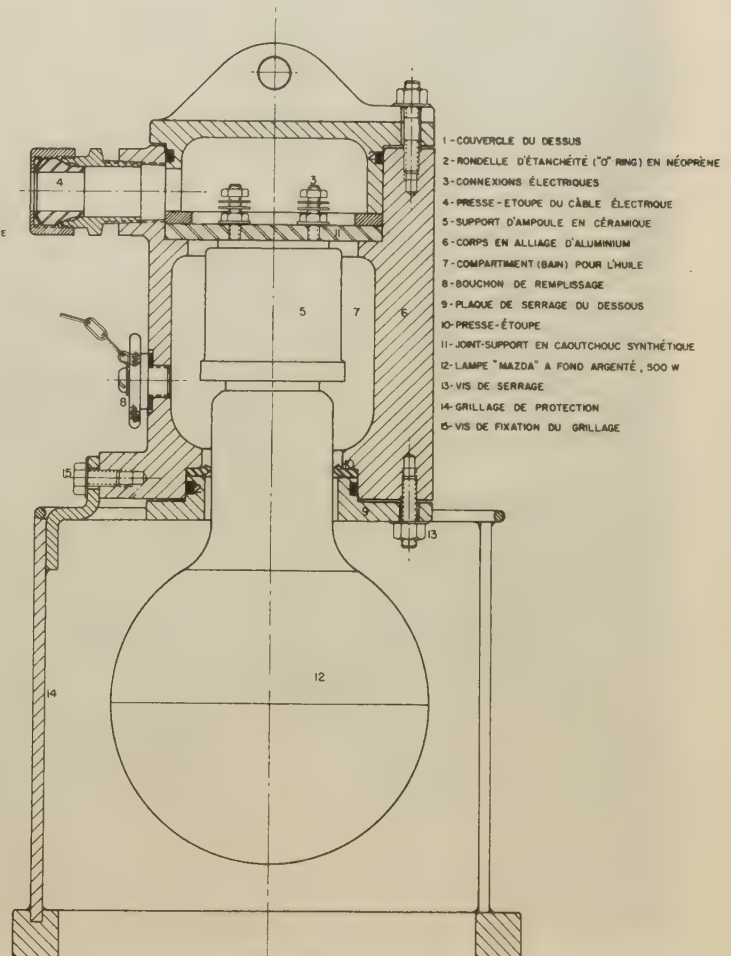


Fig. 4. Lampe de pêche immergeable du type "Hago", fabrication canadienne d'Electro-pêche. / Design of a submerged lamp of the type Hago; Canadian manufacture by Electro-pêche, /

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Fig. 5. Génératrice de 5 000 W, 120 V, couplée d'une unité de transformation pour obtenir une tension de 28/32 V. Détails du transformateur: [Generator of 5 000 W, 120 V, coupled with a transformation unit to obtain 28/32 V. Details of the transformer are as follows:]

- A - Voltmètre indiquant la tension aux ampoules
- B - Autotransformateur permettant d'obtenir la tension voulue
- C - Réceptacles de fiches mâles de 25 ampères pour la baladeuses
- D - Réceptacles de fiche mâle de 100 ampères pour le platier

Nos différents essais nous ont convaincus qu'il serait souhaitable de pouvoir installer ce matériel sur un bateau d'une longueur maximale de 6 m ayant la forme de l'embarcation "porte-feu" utilisée par les senneurs canadiens de la Colombie-Britannique.

3 METHODE DE PÊCHE

Les bateaux québécois qui pratiquent cette pêche, sont de type senneur d'une longueur de 27 m. Ces senneurs sont équipés de poulie motrice destinée à la manoeuvre de la senne tournante, filet d'une longueur de 440 à 495 m sur 36 à 70 m de chute. Ils sont également équipés d'un sondeur vertical et d'un sondeur orientable. Ces sondeurs permettent de localiser et de suivre les mouvements des bancs de poissons.

Dès que les sondeurs repèrent le poisson, le senneur éteint ses feux. Il l'annonce par radio au bateau "porte-feu" qui jette l'ancre à l'endroit indiqué. Le porte-feu allume alors ses lampes et entraîne avec lui le poisson attiré par la lumière. Les lampes sont immergées à des profondeurs variant selon l'état de la mer, la phase lunaire et la profondeur du lieu.

Après une période de temps variable - $\frac{1}{2}$ à 2 heures - l'intensité de la lumière est réduite graduellement dans le but de concentrer le poisson autour du porte-feu. Parfois pour faciliter le seinage, il nous est arrivé de diminuer la profondeur d'immersion des lampes - tout en réduisant l'intensité de la lumière - de façon à favoriser une remontée du banc de poisson.

Lorsque les opérations d'illumination sont terminées, le senneur se rapproche du porte-feu et encercle le poisson en jetant sa seine tournante autour du porte-feu dont les lampes restent allumées. Le porte-feu lève son ancre, puis est amené doucement vers le centre du filet, de façon à éloigner le poisson de son ouverture. En général, le porte-feu éteint ses lampes et sort de la seine seulement lorsque les margouillots sont montés: l'opération du boursage de la seine est alors terminée.

4 FACTEURS INFLUENÇANT LES REACTIONS DES POISSONS A LA LUMIERE

L'influence de certains facteurs météorologiques et océaniques motivèrent le choix de notre matériel de pêche à la lumière et le protocole de nos essais. Ces facteurs sont: la limpidité des eaux, l'état de la mer, la force du vent, les courants et la température des eaux.

Comme les eaux du golfe Saint-Laurent sont en général très troublées (mesure au disque de Secchi: de 3,5 à 11 m; Lacroix et Méthot, 1967) nous avons opté pour un ensemble de lampes immergées de 2500 W à 3500 W. Afin de déterminer l'absorption de la lumière produite par nos lampes, nous avons effectué, durant nos essais, des mesures d'intensités lumineuses à l'aide d'un photomètre sous-marin. Nous savons maintenant qu'à 6 m, il ne nous reste que le dixième de la lumière produite par nos lampes, et qu'à 16 m sous le platier la limite de sensibilité de la cellule photo-électrique est dépassée.

Ceci nous a amenés à placer nos deux baladeuses de chaque côté du porte-feu, et presque toujours à une plus grande profondeur que le platier, afin d'élargir la zone d'éclairement.

La profondeur d'immersion des lampes était choisie en fonction du moment de la nuit. Au crépuscule et au lever du jour, nous descendions le platier et les baladeuses à une plus grande profondeur qu'en pleine nuit (parce que le hareng monte près de la surface la nuit). Même au moment de jeter la seine, le platier et les baladeuses ont toujours été maintenus, suivant l'état de la mer, à deux mètres ou plus; cela afin d'éviter les mouvements désordonnés des lampes et d'empêcher les variations d'illumination trop brusques, variations qui peuvent nuire au rassemblement des poissons et même les effrayer, comme nous l'avons constaté à plusieurs reprises.

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Au cours de presque tous nos essais, nous avons graduellement diminué la tension effective de nos lampes de 24 à 16 V. Cette baisse de tension destinée à concentrer le poisson se fait sans à-coup pour ne pas brusquer les mouvements des poissons. Cependant, il nous est arrivé de voir se produire une déconcentration par suite d'une baisse de tension. Nos lampes produisent une lumière très blanche sous une tension effective de 24 V; cette lumière devient jaunâtre à partir de 18 V. Lorsque nous dûmes attendre notre seigneur, nous avons remarqué qu'il était facile de maintenir une concentration de harengs sous une lumière jaunâtre quand l'essai se déroulait en pleine nuit mais qu'il en était autrement quand l'essai se déroulait à l'aube.

Nos expériences eurent lieu à la fin de l'été et durant l'automne 1966, période durant laquelle la mer est agitée. Nos résultats en furent affectés, car les seigneurs ne peuvent manoeuvrer leur filet quand la mer est trop agitée. Ces bateaux travaillent rarement quand les vagues ont un creux supérieur à 1,50 m et lorsque la vitesse du vent est supérieure à 25 km/h. Quand le seigneur peut manoeuvrer sa seine, il est également possible au porte-feu de mettre ses lampes à l'eau.

Des essais ont été effectués après une tempête de trois jours pendant laquelle la vélocité du vent avait atteint 110 km/h. Nous avons alors à subir une très forte houle et les senneurs éprouvèrent des difficultés à se servir de leur seine, même si la force du vent était très réduite.

Nous avons également travaillé dans une zone où les courants étaient très intenses. Dès que les lampes étaient allumées, nous pouvions voir des poissons s'approcher de la lumière, mais ces poissons, entraînés par les courants sortaient de la zone d'attraction.

A plusieurs reprises, la détection faite pendant le jour nous indiquait une concentration de poisson à profondeur constante. Pendant la nuit, ce poisson venait parfois à la surface sous l'action de la lumière, mais il n'était pas toujours possible de le faire monter. Nous avons enregistré quelques bathythermogrammes durant nos essais, mais nos données sont trop peu nombreuses pour conclure à un effet de la thermocline. Les migrations verticales du poisson semblent y être liées.

5 REACTIONS DES ESPECES MARINES A LA LUMIERE

5.1 Le hareng (*Clupea harengus* L.)

Dès nos premiers essais, nous avons constaté que le hareng était vraiment attiré par la lumière. Après quelques minutes d'illumination seulement, le hareng commençait déjà à sauter hors de l'eau dans le halo de la lumière. Par la suite, il se rapprochait du porte-feu en nageant très rapidement près de la surface et à quelques mètres du bateau, il plongeait sur les lampes. Au tout début de nos essais, nous avons dû effectuer des trous dans la grille protectrice du platier parce que le hareng se maillait et empêchait la lumière de passer. Le plus souvent, cependant, il se concentrait dans un rayon de 100 à 150 m autour du porte-feu, sous le platier et sensiblement à la même profondeur.

La plupart des harengs attirés par la lumière étaient adultes (Tableau I et Fig. 6). A trois reprises, nous avons rencontré des harengs juvéniles, mais c'était toujours à de faibles profondeurs. Il faut signaler que durant un de nos essais, nous avons éprouvé une certaine difficulté à maintenir la concentration de harengs sous nos lampes. C'est durant cet essai que nous avons obtenu une longueur totale moyenne très basse et la gamme de longueurs la plus étendue de nos échantillons; il s'agissait de harengs qui avaient presque fini de frayer.

5.2 Autres espèces attirées par la lumière

Le maquereau (*Scomber scombrus* L.) est la seconde espèce en abondance que nous ayons capturée à l'aide de nos lampes. Nous avons capturé une centaine de gros maquereaux (de 38 à 46 cm) à chacun des coups de seine, cependant qu'un coup de seine exceptionnel permettait la capture de 4.000 individus.

TABLEAU I - Mesures effectuées sur le hareng
au cours de nos essais de pêche
au feu en 1966

Date	Position long.: O. lat. : N.	Nombre	% en frai	Longueurs totales moyennes (cm)	Poids moyen (g)
19 août	64° 39' 48° 18'	23	87	33,9	315
20 août	64° 28' 48° 22'	38	63	31,6	254
20 sept.	61° 50' 47° 08'	100	69	31,9	278
26 sept.	61° 43' 47° 20'	100	-	12,7	17
19 oct.	62° 05' 47° 25'	68	80	31,4	252
20 oct.	62° 05' 47° 25'	185	53	32,0	242
24 oct.	62° 04' 47° 27'	100	18	28,7	186
26 oct.	61° 08' 47° 48'	86	63	33,4	265

Par contre, nous avons vu fréquemment une quantité beaucoup plus grande de jeunes maquereaux de 15 à 25 cm apparaître très rapidement autour du porte-feu. Nous en avons capturé à l'aide d'un salabre durant la plupart de nos essais et il arrivait que ces petits maquereaux se maillaient dans la seine en assez grand nombre.

A plusieurs reprises, nous avons capturé, en même temps que le hareng et le maquereau, un assez grand nombre de morues (Gadus morhua L.) de tailles petite et moyenne. Deux espèces de plies ont aussi été attirées par la lumière: la plie rouge (Pseudopleuronectes americanus Walbaum) et la limande à queue jaune (Limanda ferruginea Storer). Quelques goberges (Pollachius virens L.) et deux énormes mûles communs (Mola mola L.) ont été seïnés également. Une grande quantité d'encornets (Illex illecebrosus Lesueur) ont régulièrement été capturés par la seine, mais nous avons rarement pu observer leur comportement vis-à-vis la lumière, l'encornet ne s'approchant pas de nos lampes et restant plutôt dans le halo de la lumière produite.

6 RESULTATS DES ESSAIS DE PÊCHE AU FEU

Nous avons pu effectuer 23 essais de pêche à la lumière du 16 août au 29 octobre 1966, grâce à la collaboration libre de trois senneurs des Îles-de-la-Madeleine. Les essais ont été faits à l'entrée de la baie des Chaleurs et dans les eaux des Îles-de-la-Madeleine.

Quatre essais furent vains par suite de défauts du matériel de pêche au feu et de l'absence de senneur.

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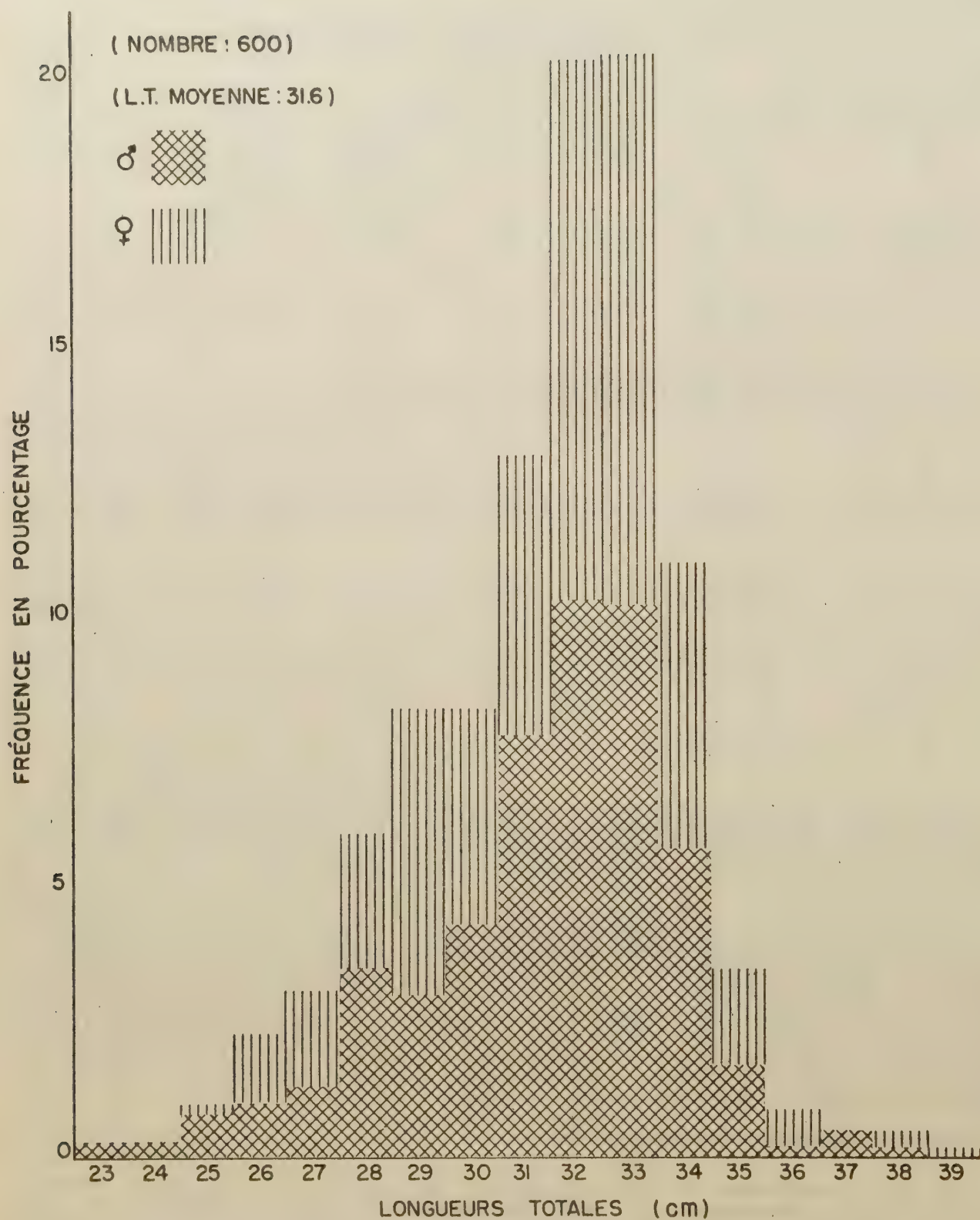


Fig. 6 Distribution des classes de longueur de harengs capturés au cours des essais de pêche au feu en 1966

TABLEAU II - Caractéristiques des sorties en mer pour les essais de pêche à la lumière en 1966

Date	Position long.: O. lat.: N.	Profon- deur (m)	Lune	Détec- tion	Vent (km/h)	Nébu- losi- tés	Illumination				Capture effective (possible) en tonnes	Remarques	
							tension (volts)	durée (min.)	profondeur (m)				
									B'	B"			P
Nuit 18/19 août	64° 39' 48° 18'	100	N. L. 1e 15	A	16	0	24 20 16	30 10 10	20 10 4	20 10 4	40 (90)	Importantes déchirures de la seine au lancement. Boursage en 52 minutes.	
Nuit 19/20 août	64° 28' 48° 22'	42	N. L. 1e 15	A	14	0	25 22 20	45 35 40	10 6 6	10 6 6	25 (75)	Perte du bout de la rallonge de la ralingue avant. Boursa- ge en 32 minutes.	
Nuit 19/20 août	64° 27' 48° 23'	51	N. L. 1e 15	A	13	0	24 22 20	40 20 10	10 6 6	10 6 6	30 (50)	Le senneur tourne trop court. Boursage en 15 minutes.	
Nuit 14/15 sept.	61° 43' 47° 13'	22	N. L. 1e 14	B	8	0	25 22 20 18 16	40 20 15 15 30	10 6 2 2 2	6 4 4 4 4	6 (?)	Petits harengs de 12 à 20 cm. Difficultés de manœuvre. Boursage en 25 minutes.	
Nuit 20/21 sept.	61° 50' 47° 03'	34	P. Q. 1e 21	B	8	0	24 24 20 20	25 50 20 20	10 20 10 5	5 10 10 5	25 (25)	Bonne synchronisation du sen- neur et du porte-feu. Boursa- ge en 15 minutes.	
Nuit 20/21 sept.	61° 46' 47° 06'	31	P. Q. 1e 21	B	16	0	24 22 20	30 10 20	10 5 5	5 5 5	5 (40)	Le porte-feu sort de la seine au début du boursage. Boursa- ge en 13 minutes.	
Nuit 21/22 sept.	61° 42' 47° 05'	31	P. Q. 1e 21	B	9	0	24 20	30 10	20 10	10 10	- (25)	Le senneur en difficulté, doit retourner au port.	
Nuit 26/27 sept.	61° 43' 47° 20'	18	P. L. 1e 29	B	8	0	25 25 23	40 35 10	10 6 6	10 6 6	10 (10)	Petits harengs de 12 à 20 cm. Boursage en 20 minutes.	

TABLEAU II - Caractéristiques des sorties en mer pour les essais de pêche à la lumière
en 1966 (concluded)

Nuit 28/29 sept.	61° 00' 46° 38'	45	P. L. 1e 29	B	8	0	25	45	20	20	10	2 (2)	Après 45 minutes, la g�n�ralit� s'est arr�t�e. Boursage en 15 minutes.
Nuit 8/9 oct.	62° 09' 47° 15'	34	D. Q. 1e 7	B	18	0	24	35	10	10	6	10 (25)	Nombreuses difficult�s de man�uvre durant le lancement de la seine. Boursage en 30 minutes.
Nuit 19/20 oct.	62° 05' 47° 24'	30	P. Q. 1e 21	C	8	0	25	15	6	6	3	38 (30)	Fonds accident�s, nombreuses d�chirures dans la seine. Bonne synchronisation des 2 bateaux. Boursage en 18 minutes.
Nuit 19/20 oct.	62° 05' 47° 25'	33	P. Q. 1e 21	C	16	1	25	15	2	2	4	25 (40)	Le senneur tourne trop court. Boursage en 45 minutes.
Nuit 24/25 oct.	62° 03' 47° 27'	30	P. L. 1e 29	B	8	1	25	45	8	8	4	2 (20)	Le senneur tourne trop court et laisse une partie de la seine sur le pont du bateau. Boursage en 40 minutes.
Nuit 24/25 oct.	62° 04' 47° 27'	33	P. L. 1e 29	B	8	1	25	30	20	20	10	25 (25)	La concentration de poisson a diminu� quand la tension est arriv�e � 18 volts. Boursage en 15 minutes.
Nuit 26/27 oct.	61° 08' 47° 48'	30	P. L. 1e 29	C	6	6	24	40	8	8	4	5 (20)	Le porte-feu sort de la seine. au d�but du boursage. Courant et houle tr�s forts. Boursage en 20 minutes.

D tection: A: nulle (traces); B: faible et  parse; C: bonne
N bulosit : 0   10, soit couverture de 0   100%.
B' - B'': Baladeuses; P: Platier.

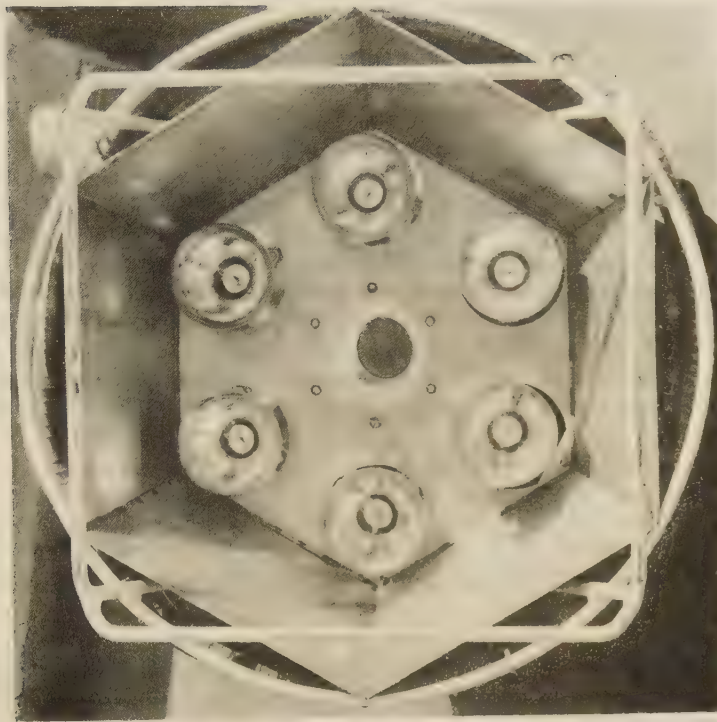


Fig. 7a Platier de fabrication canadienne, comprenant 6 lampes de 500 W. Au centre, l'oscillateur orientable

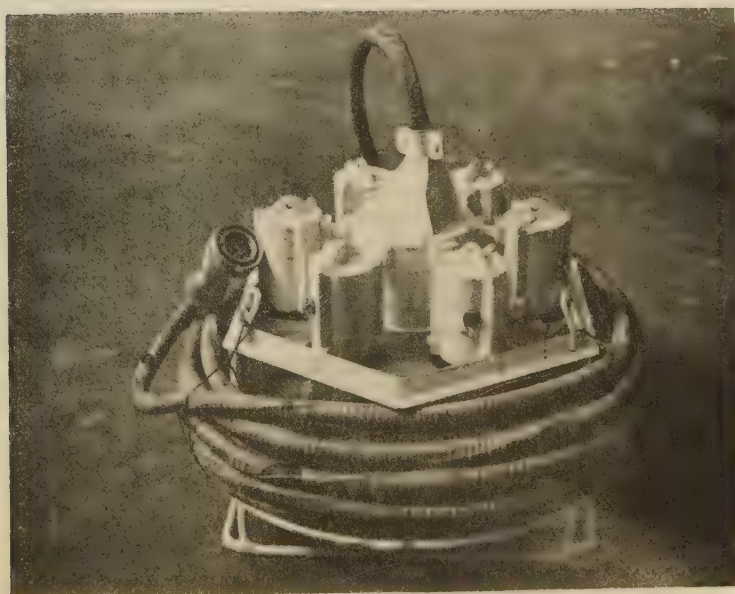


Fig. 7b Vu de l'arrière du platier, au centre les connexions électriques et l'oscillateur orientable

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Quatre autres essais n'ont pu être terminés par les senneurs. Nous étions incapables de leur indiquer la quantité de hareng concentrée sous et dans le halo de nos lampes. Quand le hareng ne monte pas en surface, le lampiste ne peut en évaluer la concentration; il est nécessaire alors d'avoir un sondeur pour en faire l'évaluation et nous n'en avons pas.

Nous avons eu 15 essais terminés par les senneurs. Parmi ces essais, 7 ont rapporté de 25 à 40 tonnes de harengs. Cinq d'entre eux furent effectués à la suite de détect-ions nulles, ou faibles et éparses. Sans l'utilisation des lampes, aucun des senneurs n'aurait essayé de jeter sa seine à la suite de telles détect-ions. Nous aurions pu faire 5 autres essais avec d'aussi bons résultats, mais nous avons éprouvé des diffi-cultés dans la synchronisation des opérations du porte-feu et du senneur. Sur ces 5 essais possibles, trois ont été faits à la suite de détect-ions faibles et éparses. Deux autres essais n'ont rapporté que des petits harengs de 12 à 20 cm, harengs non retenus par le filet. Un seul essai nous a permis de capturer deux tonnes de maquereaux, quantité comparable à celle obtenue par les senneurs durant le jour au même endroit. (Tableau II).

7 CONCLUSION

A la suite des essais effectués, il est évident que l'emploi d'une seine-bourse de 600 m sur 70 de chute ou plus permettrait une plus grande facilité de manoeuvre et de meilleures captures.

La manoeuvre de ce filet pourrait également être améliorée en terminant les deux côtés de la seine par des pièces triangulaires appelées "aile avant" (côté poche) et "aile arrière" (côté opposé à la poche).

Par suite de l'essai de la lampe sous-marine de fabrication canadienne, de son utilisation durant 335 heures sans difficulté technique, nous pourrions bientôt expérimenter un nouveau platier de forme hexagonale comprenant 6 de ces lampes couplées en deux séries triangulaires de trois unités et à commande autonome. Afin de pouvoir renseigner les senneurs sur la concentration du poisson attiré par la lumière, nous avons incorporé un sondeur orientable au centre de ce platier. (Fig. 7a and 7b).

La pêche au feu présente de nombreux avantages. Elle est économique en dépit de la dépense initiale d'armement, car le coût d'installation peut être rapidement amorti par un rendement accru de la pêche, surtout lorsque le poisson est dispersé. Elle permet également des captures en des endroits où, malgré une détect-ion facile du poisson, il est impossible de le pêcher parce qu'il reste en profondeur. La pêche au feu permet en outre de ramener le poisson aux usines de transformation dès le matin, avant qu'il n'ait eu le temps de se détériorer à la chaleur.

A l'instar de Kurc (1963) disons en terminant que "si la pêche à la lumière ne peut résoudre toutes les difficultés, ni constituer l'introuvable "panacée" qu'attendent toujours certains professionnels de la pêche, elle apporte des garanties certaines d'un rendement meilleur et d'une économie substantielle".

C REFERENCES

- Gellert, A., Evolution de la pêche à la lumière dans les lacs africains. In Modern Fishing gear of the world, Fishing News International and Fishing News (P's), London, Fishing News(Books) Ltd., vol.2:573-7
1964
- Da Mianca, P. et F. Polimino, Essais de pesca com luz (Essais de peche à la lumière) Notas mineiras, Cent.Biol.piso., (44):37 p.
1965
- Dragesund, B., Reactions of fish to artificial light, with special reference to large herring and spring herring in Norway. J.Cons.perm.int.Explor.Mer, 23(2): 213-27
1958
- Kirillov, V.M., Purse seining with lights from a motor dory. Ryb.Khoz., 37(1):27-31
1961
- Kisslev, O.T., Observations on behaviour of fishes in the Barents Sea with the aid of submarine apparatus. In Soviet fisheries investigations in north European seas, Moskva, VNIRO/PINRO, pp.457-61
1960
- Kuro, G., La pêche à la lumière en Atlantique. Sci.Pêche, (113):13 p.
1963
- Kuro, G. et A. Percier, La pêche à la lumière. Les essais de l'Institut des Pêches. Bull.Cent.Etnd.Rech.scient.Biarritz, 2(3):313-25
1959
- Kusaka, S., Fish gathering effects and submarine illumination of the incandescent and fluorescent mercury-vapour lamps. Bull.Jap.Soc.scient.Fish., (1)17-21
1959
- Lacroix, G. et L. Méthot, Deuxième catalogue des échantillons de zooplancton du musée de la Station de biologie marine (1962-1964), addition au premier catalogue (1951-1961) et sommaire des observations pour la période 1951-1964. Can.Inf.Stn biol.mar.Grande-Rivière, 41:1-70
1967
- Lindqvist, A.A., Fiske med Ljus (Pêche à la lumière). Svenska Vastkustfisk., 24(33):502-5
1963
- Nikorodov, I.V., Lev ryby na svet (Pêche à la lumière. Théorie et pratique) Moskva, Rybnoe Khoziaistvo, 166 p. (Traduction anglaise Transl. Fish.Lab., Lowestoft)
1968
- Schärfe, J., Ueber die Verwendung künstlichen Lichtes in der Fischerei. Protok. FischTech., 2(8):30 p.
1953
- Anon, Fixed net fishing with lamp lures. Fish.Newsl., Aust., 8(5):19
1949

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OBSERVATIONS ON THE ATLANTO-SCANDIAN HERRING
WITH RESPECT TO SCHOOLING AND REACTIONS TO FISHING GEAR

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Abstract

Observations of the changing behaviour patterns of herring as they migrated from Iceland to the coast of Norway during the winter of 1966/67 are described. Off the coast of Iceland the fish formed relatively loose schools which were successfully fished with a midwater trawl. In the off-shore Atlantic waters and off the Norwegian coast successful midwater trawling efforts were rare.

OBSERVATIONS SUR LE COMPORTEMENT DU HARENG ATLANTICO-SCANDINAVE
EN MATIERE DE FORMATION DE BANCS ET DE REACTION AUX ENGINS DE PECHE

Résumé

La communication décrit le résultat d'observations sur les modifications du comportement de harengs durant leur migration d'Islande vers les côtes norvégiennes durant l'hiver 1966-1967. Au large de l'Islande, les harengs constituaient des bancs relativement peu serrés, pêchés avec succès au chalut pélagique. Par contre, en plein Atlantique et au large de la côte norvégienne, le chalut pélagique a rarement donné de bons résultats.

OBSERVACIONES DEL ARENQUE ATLANTICO-ESCANDINAVO RELACIONADAS CON
RESPECTO A LA FORMACION DE CARDUMENES Y LAS REACCIONES
ANTE LOS ARTES DE PESCA

Extracto

Se describen observaciones de los cambios de las modalidades del comportamiento de arenque en emigración desde Islandia hasta la costa de Noruega durante el invierno de 1966 a 1967. En aguas de Islandia el arenque formaba cardúmenes relativamente desperdigados que se pescaban satisfactoriamente con artes pelágicos. En las aguas atlánticas de las proximidades de Noruega era raro que dieran buenos resultados las tentativas de pesca con artes de arrastre pelágicos.

1 INTRODUCTION

The behaviour of herring in relation to midwater trawling has received considerable attention in recent years. Research vessels engaged on the development of pelagic trawls as well as commercial midwater trawlers are nearly always equipped with echo and net sounders and recordings of these devices have provided information on reactions of fish to fishing gear. Until 1965, trial and commercial fishing for herring by German boats exploited only the shelf group of herring distributed in the North Sea and the adjacent shallow seas.

Although these investigations and observations on fish behaviour did not result in establishing definite laws for the reaction of herring to stimuli caused by fishing gear, a certain number of rules of behaviour were formed. Mohr (1964a,b) found that during the day, hibernating non-spawners in deeper water (Skagerak, Norwegian Deep) form extensive stationary layers at 150 to 250m below surface and sometimes move in dense schools at depths of 50 to 150m. These fish are not too difficult to catch provided that the towing speed is about 3.5k and the opening of the net is at least 15-20m in each direction. The fish maintain a clearance of 5-6m from the lines framing the net mouth and therefore a net with an opening of only 10m height or width is altogether avoided by the fish. During the night, the herring are scattered near the surface; at this time and during their vertical migration at dusk and dawn, they are more alert and cannot be caught easily by the trawl.

1.1 Recovering spents and early pre-spawners

In summer and autumn, recovering spents and early pre-spawners form numerous small schools in the shallow water of the feeding grounds. These shoals require a high towing speed and a big light net, otherwise the small schools disperse completely before the net reaches them; good catches can only be made of occasional bigger and denser schools in which the fish hamper each other's vision and reaction.

1.2 Pre-spawners of a later stage of maturity

These fish usually form denser concentrations near the bottom during the daytime and can then be caught successfully with heavier pelagic or semipelagic gear. These fish keep a clear distance of 2-4m from the framing ropes and net panels. On the approach of the net the herring often go right down to the sea bottom, thus necessitating a net strong enough to risk contact with the bottom.

1.3 Herring with mature eggs or sperm

Herring with mature eggs or sperm, and to a lesser degree, partly spents and freshly spents, form very dense concentrations near the bottom. For the most part these fish remain quite passive and often do not show any reaction to the gear. They can be caught with all types of gear, even those which proved ineffective for all the other stages of herring. A high towing speed is not required for these herring ready to spawn.

As mentioned earlier these observations refer to the shelf herring groups. No investigations had hitherto been made on the reactions of the large oceanic herring which differ markedly in size and biological make-up from the shallow-water group. Pelagic trawling for these Atlanto-Scandian herring was not begun until 1965 by the commercial trawlers. In 1966 and 1967 two trips were made by the research vessel WALTHER HERWIG which was equipped for observations on the behaviour of this herring.

According to Devold (1961) and Shmarina (1965) the feeding grounds of adult Atlanto-Scandian herring are along the "polar front" area of the Norwegian sea and above the thermocline. In late summer they penetrate the thermocline and are found by day at depths down to 500m in the Arctic water of the East Iceland Current; at night they move up to the surface layer. In autumn they gather in a relatively small area east of Iceland where they stay until late December or early January when the spawning migration begins. So long as the fish are in the Arctic waters (3° - 5° C) they travel at a speed of 5 to 7 nautical miles in 24h, but after penetrating the front of the Atlantic water (6° - 8° C) they travel much faster

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at a speed of 20 to 40 miles per day. On reaching the Norwegian coastal waters, the big schools disperse or scatter into small schools. Spawning takes place in February and March about a month after their arrival on the Norwegian west coast. The spent fish then migrate out to the open sea again.

Apart from the biological differences, this type of herring is much bigger in size than the North Sea shelf herring, the average length of adult fish being 33 to 34cm. As the swimming speed and endurance of fish depend upon their size, this factor is important in fishing operations.

2 EQUIPMENT AND INVESTIGATIONS OF THE RESEARCH VESSEL WALTHER HERWIG

The first trial fishing trip was undertaken in November and December 1966 when the herring had gathered east of Iceland; the second trip took place in January and February during the spawning migration and the arrival of the schools on the Norwegian coast. Big pelagic trawls of 1 600 and 2 000 meshes circumference round the net mouth were used and observations made with a sonar (horizontal echosounder), a shipboard echosounder, and net sounder (the latter sometimes equipped with 6 transducers) fixed at various parts of the gear. It was therefore possible to observe the distribution of fish in front of the net, between the wingtips, vertically and horizontally in the net opening, below and above the net mouth and in the forepart of the net (see Fig. 1 and 2). A detailed description of the gear and sounding apparatus is given by Schärfe (1966;1967).

At each place where hauls were conducted the water temperature was measured with a bathythermograph and samples of fish were taken and analyzed for information on length/frequency distribution, maturity stages and stomach contents. The identity of the curves of length/frequency distribution confirmed the fact that in both trips herring of the same stock had been fished (see Fig.3). The stage of maturity had not changed much in the time between the two voyages as seen in Table I.

TABLE I - Maturity stages of herring

Maturity stage	a (n=300)	b (n=465)
	Percentage	
I	-	-
II	1.7	1.1
III	1.0	1.3
IV	12.7	2.6
V	84.0	91.8
VI	0.3	3.0
VII	-	-
VII/II	1.3	0.2

a=fish caught in November and December east of Iceland, and b=fish caught in January and February during the migration and at the Norwegian coast.

Despite this fact, the fish caught during the second trip were much thinner and looked like spents although they were not. Their stomachs were always empty; they had used up their fat during the travel and consequently lost much weight.

3 BEHAVIOUR OF THE ATLANTO-SCANDIAN HERRING IN THE WINTER OF 1966/67

From the information collected by the research vessel from November to February 1966/67, three phases of pre-spawning behaviour of the Atlanto-Scandian herring could be distinguished:

- congregation on the coast of Iceland before the spawning migration;
- migration from Iceland to the Norwegian coast;
- dispersion of the shoals at the banks and in the coastal waters of the Norwegian west coast.



Fig. 1. Reaction of the dispersed layers of herring off Iceland toward the net. In its path the fish are concentrated by the bridles. The general flight reaction is downward. The fish in the net mouth are chased by the bobbins into the upper half.

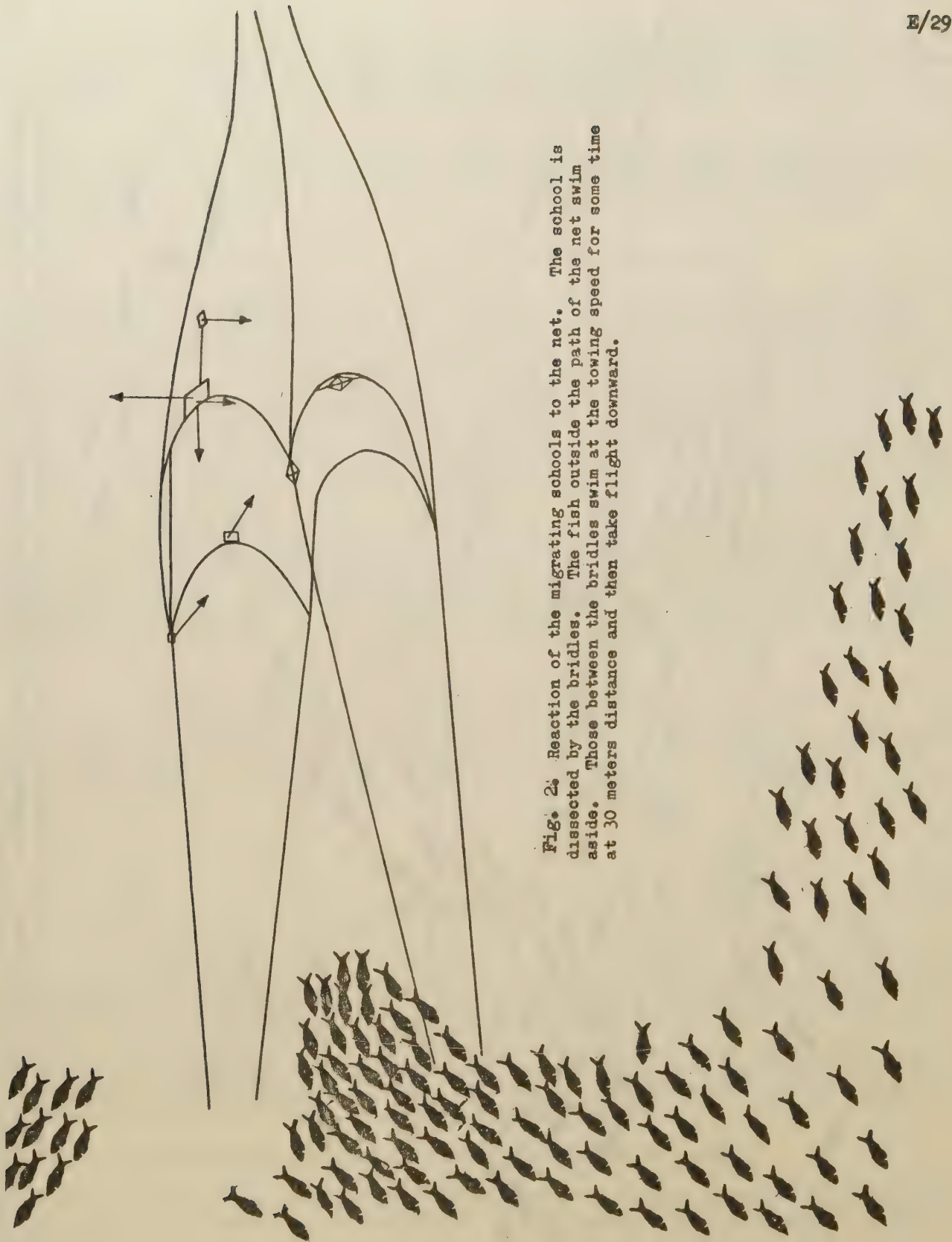


Fig. 2. Reaction of the migrating schools to the net. The school is dissected by the bridles. The fish outside the path of the net swim aside. Those between the bridles swim at the towing speed for some time at 30 meters distance and then take flight downward.

The behaviour patterns of most importance in capture are those of schooling and reactions to fishing vessel and gear. Observations in these aspects are dealt with in this paper.

3.1 Schooling

3.1.1 Schools east of Iceland. Concentrations of herring in this area extended horizontally for at least some hundred meters and often some miles. They were distributed vertically in a cloudy layer of different densities usually to a depth of 100 to 150m. These concentrations were relatively stationary except for diurnal vertical movements. During night time the upper edge of the herring layer was only 50 to 100m below the surface, whereas during the day it descended to 250 to 300m. Temperature remained uniformly between 3.4 to 3.5°C. The average density of these concentrations, estimated from catches, was 500 to 1 000 herring per 1 000m³ water. It should be noted however that this estimate, calculated by measuring the column which the net had punched out of the trace, cannot be considered accurate, but it compares favourably with the findings of Scherbino and Truskanov (1966) obtained by means of underwater photography and echo-sounding operations.

3.1.2 Migrating schools. Observation of the migrating schools was possible only when they had already reached Atlantic waters. Their migration in the Arctic waters had occurred in the interval between the two trips of the research vessel. The temperature in the depths where the herring travelled was between 6.5°C and 8.5°C. The migrating schools presented a very characteristic shape in the echograms, showing sharply demarcated contours which distinguished them from all other fish traces occurring from time to time. The schools appeared as vertically rising rockets in the echograms (see Fig.4). These shoals were, in fact, oval shaped and usually twice as long horizontally as vertically, the vertical extension ranging from 50 to 150m, the horizontal thus being 100 to 300m. In some extreme cases, the shoals were almost ball shaped. During day and night these shoals had the same compact appearance and sharp contours, and were obviously travelling in the predetermined direction. Diurnal vertical movements obviously did not occur or were within a small range. The schools when undisturbed had their upper edge 30 to 100m below the water surface. The densities of these schools were much higher than those of the fish concentrations off Iceland. During one haul, when the fish appeared to be confused and were overtaken by the gear without showing directed flight reactions, it was estimated (from the water column filtered out of the shoal in relation to the catch) that there were about 5 000 fish per 1 000m³. As many fish escaped before the net's approach, an estimate of 10 000 fish per 1 000m³ might not be too high.

3.1.3 Schools off the Norwegian coast. When the fish reached the banks off the Norwegian coast, these dense migrating schools became stationary, dispersed to some extent or even scattered completely during the night and formed cloudy layers in various depths. Sometimes two separate layers of herring could be distinguished, the upper one at about 50 to 100m depth and the lower at 150 to 250m below the surface. The hydrographical conditions did not explain the formation of these two layers because the temperature was 7°C to 8°C without a thermocline. The fish in these layers showed different reactions to the gear, as will be explained later. In the morning, the layers partly fused again to form small migrating schools which travelled towards the coast yet a good deal of the cloud-like appearance of the traces remained during the day. On some occasions during day and night, the fish were distributed over big areas very close to the surface, and could be detected only with the sonar. Not a single fish was detected below the ship and they could not even be observed visually as they kept at some distance from the ship. Nevertheless, purse seiners and drifters made very good catches in these areas and gannets were frequently seen swooping for fish close to the surface.

3.2 Reactions to vessel and gear

3.2.1 Herring east of Iceland. Congregations of herring in the waters east of Iceland were not too active, nor reactive to stimuli. Ships passing the concentrations did not cause an appreciable movement, or at least one which could be observed. The fish did not appear to take flight in a horizontal direction before the approaching net, because in the forward directed transducer of the net sounder they could be seen continuously

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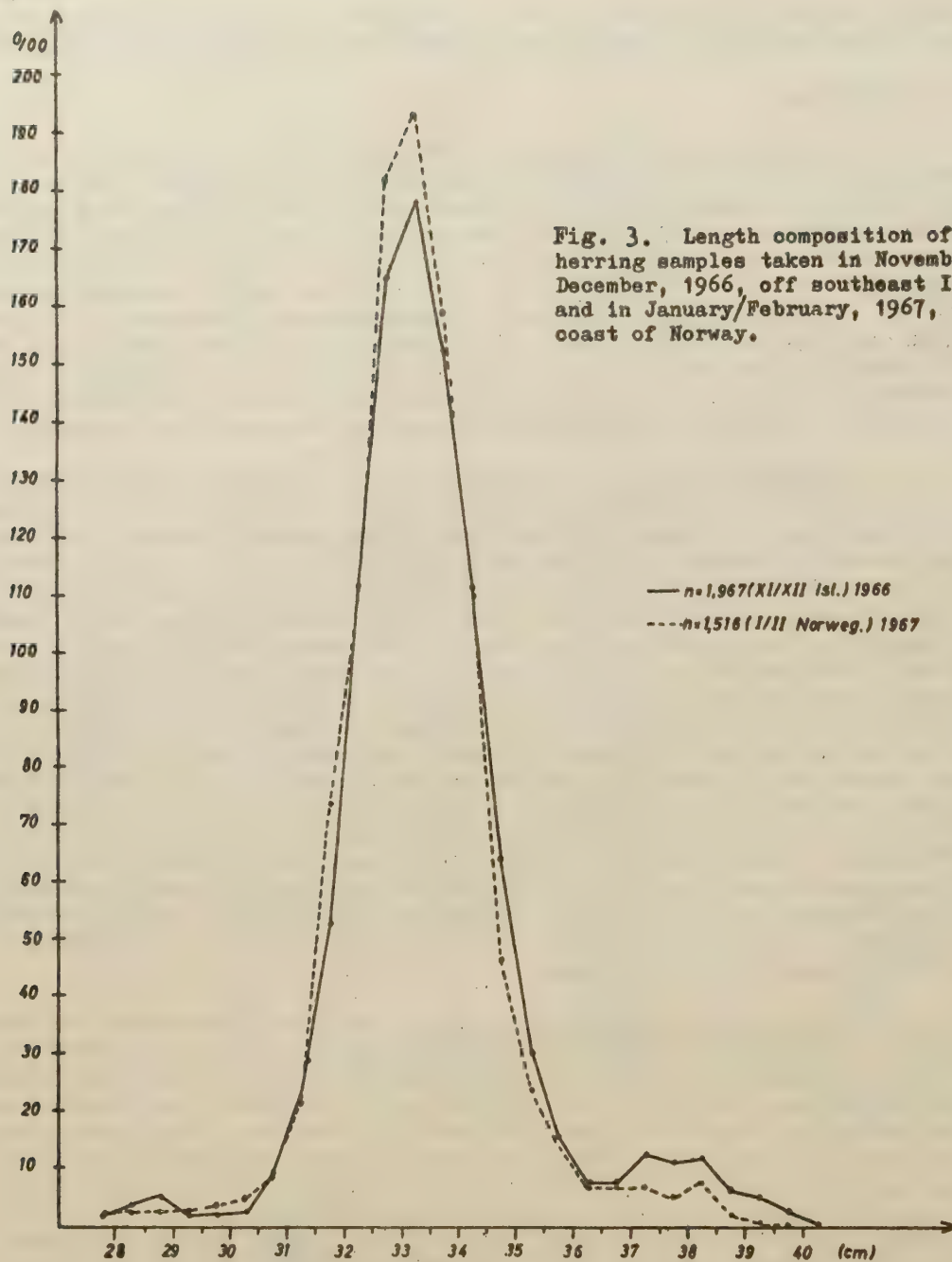


Fig. 4. Appearance of a migrating school in the ship's sonar ("rocket"), and the actual shape of the school.

approaching the gear. (Actually, the movement is contrary: the gear approaches the fish). But a general flight took place in a downward direction. Even when fishing through exceptionally dense concentrations, only in a few instances could some fish be observed above the net. Dense masses of fish were usually present below the net at about 20m below to the footrope. The most effective catching technique was therefore to allow the net to sink when towing through a concentration. In the net mouth the fish were mostly concentrated in the upper half at about 7 to 10m away from the bobbins of the footrope (see Fig.1). Fishing in the daytime with an exceptionally large net (2 000 meshes circumference, opening 40x20m) was most successful. In this particular case, a speed of 3.5kn was sufficient to "out-manoeuvre" the fish (Schärfe, 1967). With smaller nets, a somewhat higher speed was required. Fishing with pelagic trawls was very successful in these concentrations and resulted in catches of some 20 to 100 tons per one hour haul.

3.2.2 Migrating herring. During the period of migration and during the first phase, the herring move slowly through the Arctic water north and northwest of the Faroe Islands and commercial midwater trawlers obtained very good catches during the period between the two research trips. Their skippers reported that the behaviour of the fish appeared to be similar in many respects to that evident during the earlier stationary period off East Iceland. On reaching the warmer Atlantic waters the behaviour of the herring changed; they travelled at a much greater speed and showed a very sensitive reaction to the ship and gear. When a ship passed directly above the school, it caused alarm and the fish dived to a depth of 50 to 100m. The schools frequently changed their swimming direction in front of the approaching ship as evidenced by the sonar, and in some cases even divided themselves into two or more schools which took flight in different directions or scattered so completely that the formerly dense schools could not be detected again by the sonar. In the gap between ship and gear it was necessary to observe schools with the sonar directed backward, in order to change the towing direction according to the movement of the school. Success could not be guaranteed however, even when dense masses of fish were indicated by the forward directed transducer of the net sounder. At a distance of 30 to 50m from the net the fish obviously became aware of the approaching gear, even in the dark, but they swam for some time in front of the net at the towing speed and then disappeared completely, moving swiftly to the sides or downwards (see Fig.2). As the towing speed was always 3.8 to 4 kn, the swimming speed of the fish must have been considerably higher. At a depth of 20 to 50m below the net, the school could be detected again but few fish were seen above the net. Out of 25 schools located and for which the gear was shot (sometimes repeatedly) the catches were in most cases out of all proportion small compared to the strong echo traces. The fish obviously became confused in front of the trawl and only in one instance during the night was the gear able to reach them before they had re-formed into an escaping school. In this case the haul yielded more than 100 tons.

3.2.3 Herring in coastal waters. The schools of herring on approaching the coastal area, dispersed to some extent and rested at least during the night but were still sensitive to ship and gear. They were favourite targets for purse seining, the seiner keeping at a good distance from the school and surrounding it when the small bass boat, fitted with Basdic equipment had taken a closer look at it. Single boat midwater trawlers always have the disadvantage of having to pass above the school, thus making the fish react adversely. Even when fish were present in layers at different depths, the catches were usually very poor because most fish disappeared downwards when in front of the net. When two layers were present, fish were not usually caught from the upper layer but in the deeper layer at a depth of 200m (between 2 and 4 am) the fish almost completely lost their reactivity and could then be caught successfully during the early hours of the morning.

The behaviour of herring with mature gonads could not be observed because when the spawning period begins, these fish enter the area within the Norwegian fishing limits where they are inaccessible to foreign ships.

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4 DISCUSSION

Observations prove that the Atlanto-Scandian herring is very alert during its migrating stage and also during the last resting phase before spawning; they cannot be caught successfully by the present method of midwater trawling. The beginning of intensified swimming activity and sensitivity does not coincide with the actual commencement of migration but with the time of penetration from Arctic waters into the warmer Atlantic waters. This intensified activity is therefore probably due directly to the influence of temperature.

The stimuli responsible for alarming the fish are obviously not optical ones because the fish react to the gear strongly both during the day and night and at distances up to more than 30 m which are beyond visual range. Noise, turbulence and water blockage in front of the net must cause some reaction in these cases. An accidental observation suggestive of water blockage was when the net was quickly and abruptly lowered to the right depth on to a school of herring detected by the ship's sounder off the Norwegian coast. In contrast to earlier reactions, the fish entered the net mouth without dispersion and in dense masses. When the gear was hauled, it consisted of only the frame of the net mouth and a few meters of netting, the other parts of the net having been torn off during the too abrupt lowering. Soviet submarine personnel observed that herring tend to sleep occasionally at night (Anon., 1964) and this might explain why they were easily caught during certain hours of the night. While a towing speed of 3.5 kn was usually sufficient for catching shelf herring provided that the gear was large, these oceanic herring could escape at a towing speed of 4 kn when the large net opening (20 x 40 m) had approached them within 20 m. The swimming speed of the large herring in water temperature of 6° to 8°C, therefore must be considerably above 4 kn.

From these few observations it is not possible to establish whether learning is partly responsible for the sensitive and skipped reaction of the fish in avoiding ship and gear. This stock of herring has been fished very intensely in recent years from its feeding period in summer until spawning in the spring. During the time of these investigations, about 1 000 vessels are estimated to have fished for the Atlanto-Scandian herring. Devold (1961) reports that in former years, the migrating schools were very close to the surface during the night whereas in recent years they have always remained at a greater depth than 100 m.

5 REFERENCES

- Devold, F., The life history of the Atlanto-Scandian herring. ICES Herring Symposium, 1961 (40):8 p. (mimeo)
- Mohr, H., Reaction of herring to fishing gear revealed by echo-sounding. In Modern 1964a fishing gear of the world, Fishing News International and Fishing News (Eds), London, Fishing News (Books) Ltd., vol.2:253-7
- _____, Herring observations during midwater trawling in September/October 1964. 1964b Paper presented at Fourth IF-Meeting, Hamburg (mimeo)
- Schärfe, J., Reise des FFS WALTHER HERWIG in das Heringsfanggebiet Ost-Island 1966 (Seydisfjord) vom 19 November bis 18 Dezember 1966. Infn Fischw.Auslds, 13(6):230-6
- _____, Size versus speed in herring midwater trawling. Paper presented at 1967 Sixth IF-Meeting, Aberdeen (mimeo)

Scherbino, M.N. and M.O. Truskanov, Determination of the density of fish concentrations
1966 by means of acoustic apparatus. ICES Comparative Fishing Committee, CM.
1966(F3):5 p.

Shmarina, L.R., Distribution of wintering herring in the southern part of the Norwegian
1965 Sea according to temperature conditions. Spec.Publs int.NW.Atlant.Fish.,
(6):635-43

Anon., Soviet research by submarine. Wld Fishg, 13(1):40-1
1964

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STUDY OF THE SWIMMING HABITS OF FLYING FISH IN THE SPAWNING SEASON

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Abstract

This study was carried out during the period from May to August 1955, and from May to June 1962, at Tomioka, Amakusa Islands, Kumamoto Prefecture, Japan. The swimming habits of flying fish, Cypselurus opisthopus hiraii were observed and increase of the catching efficiency of the drift gillnet was tested. The results obtained from this study are as follows.

The ratio between the fish that were gilled while moving towards the seaward side and the fish moving off shore towards the landward side was found to be about 7:10 in favour of the latter at 7 to 8 p.m., 3 or 4:10 at 8 to 10 p.m., and 7:10 at 10 to 11 p.m. and after 11 p.m. about 10:10 or more. However, the final count showed that the number of the fish which were caught on the landward side of the nets was twice that on the seaward side.

It seems that in coastal waters the migration of flying fish in the spawning season is greatly influenced by the location of the spawning ground and the spawning time.

By night, over 80 per cent of the flying fish caught was found in the layer from surface to 1 m depth. After sunset, distribution of the fish was almost limited to 0-1m depth but as the night wore on, it extended down to 1-2.25 m depth and as day broke, it occurred in great abundance 0-1 m depth again. More fish swam in the upper layer from 8 to 11 p.m. during the major spawning season than at the beginning or end of the same season.

The fish are crowded in the uppermost layer, no matter how large the number of fish migrating to this spawning region may be.

ETUDE DES DÉPLACEMENTS DU POISSON VOLANT DURANT LA FRAIE

Résumé

Les observations dont il est rendu compte ont été faites de mai à août 1955 et de mai à juin 1962 à Tomioka, îles Amakusa, Préfecture de Kumamoto, Japon. L'étude portait sur le comportement en matière de nage du poisson volant, Cypselurus opisthopus hiraii, ainsi que sur les variations du rendement des filets maillants dérivants. Elle a fourni les résultats suivants.

Note: Based on the author's article on the subject in Japanese J. Michurin Biol. 2 (2)(1966).

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Le rapport entre les poissons maillés alors qu'ils allaient vers la côte et ceux qui ont été pris tandis qu'ils se dirigeaient vers le large était de l'ordre de 7/10 en faveur de ces derniers de 19 à 20 heures, de 3 ou de 4/10 de 20 à 22 heures, et de 7/10 de 22 à 23 heures, tandis qu'après 23 heures la proportion atteignait 10/10 ou davantage. Toutefois, au dénombrement final, les filets avaient pris deux fois plus du côté terre que du côté mer.

Il semble que dans les eaux côtières la migration du poisson volant lors de la fraie soit fortement influencée par l'emplacement des frayères et par l'époque de la reproduction.

La nuit, plus de 80 pour 100 des poissons volants capturés se trouvaient dans la couche allant de la surface à 1 m de profondeur. Après le coucher du soleil, les poissons se tenaient presque uniquement dans cette couche, mais à mesure que la nuit s'avancait leur distribution verticale s'étendait jusqu'à 1-2,25 m tandis qu'à l'aube on les trouvait de nouveau en grand nombre de 0 à 1 m. De 20 à 23 heures, davantage de poissons nageaient dans la couche supérieure durant le gros de la fraie qu'au début ou à la fin de celle-ci.

Aussi élevé que soit leur nombre, les poissons arrivant sur ce terrain de fraie s'entassaient dans la couche superficielle.

ESTUDIO SOBRE LOS HABITOS NATATORIOS DEL PEZ VOLADOR EN EL PERIODO DE DESOVE

Extracto

Este estudio se realizó durante el período comprendido de mayo a agosto de 1955, y de mayo a junio de 1962, en Tomioka, Islas Amakusa, Prefectura de Kumamoto, Japón. Se observaron los hábitos natatorios del pez volador Cipselurus opisthopus hiraii y se probó el incremento de la capacidad de captura de la red de enmalle de deriva. Los resultados obtenidos en este estudio son los siguientes:

La relación entre los peces que se capturaron cuando se dirigían en dirección de adentro mar y los peces que frente a la costa se dirigían hacia el lado de tierra se halló que era de unos 7:10 en favor de los últimos de 7 a 8 de la tarde, de 3 o 4:10 de 8 a 10 de la tarde, y 7:10 de 10 a 11 de la noche y después de esta hora alrededor de 10:10 o más. No obstante, el cómputo definitivo indicó que el número de peces que se capturaron en el lado de las redes orientado hacia tierra era doble que el del lado orientado hacia el mar.

Parece ser que en las aguas oosteras la migración de los peces voladores en la época de desove se halla grandemente influida por la situación del lugar y la fecha en que tiene efecto la freza.

De noche, más del 80 por ciento de los peces voladores capturados lo fueron en la capa situada desde la superficie hasta un metro de profundidad. Después de la puesta de sol la distribución de los peces casi se limitó de 0 a 1 metro de profundidad, pero a medida que avanzaba la noche la profundidad aumentó de 1 a 2,25 metros y al alba hubo una gran abundancia entre 0 a 1 metro de profundidad. En la capa superior nadaban más peces desde las 8 a las 11 de la noche durante el período principal de desove que a principios o finales del mismo período.

Los peces abundan en la capa más alta, prescindiendo de la cantidad de peces que emigran a esta región de desove.

1 INTRODUCTION

In Japan, the flying fish Cypselurus opisthopus hiraii are caught by drift gillnets, liftnets, fixed nets and surrounding nets, of which the drift gillnet yields close to half of the total catch. This fish is one of the important commercial species in the country, the total landings amounting to about 1200 tons. There are several papers published on the taxonomy and ecology of this fish. Its swimming habits during the night have been described by Tsukahara, Shiokawa and Inao (1957) while Kojima (1961) describes its swimming behaviour in the daytime.

The present author carried out experimental fishing to observe the behaviour of the fish, during the period from May to August 1955 and from May to June 1962, off Amakusa Islands on the west coast of Kyushu, Japan. The study was aimed at understanding the spawning habits of the fish and increasing the catching efficiency of the drift gillnet. The information given in the present paper is based on the results of this study.

2 MATERIAL AND METHODS

From the data collected during experimental fishing in 1955 and 1962, only material related to Cypselurus opisthopus hiraii was used in this study. The fishing was done in the same way as commercial fishing, using a boat of 1.5 tons and 6hp (see Table I).

Observations on water temperature, specific gravity and sea current were made and then the gillnet was set nearly straight. The netted fish were collected every hour and the depth and direction in which they were caught and their sex and maturity were recorded directly on the boat. Thirty fresh fish were measured in detail in the laboratory.

In the experimental fishing in 1955, a series consisting of four high "tan" nets was set at places 3 to 4km distance from the shore at right angles to the sea current. In 1962 three series of gillnets were set nearly parallel to the sea current at points 2 to 3km apart. The first series consisted of 3 high² "tan" and 3 low³ "tan" connected alternately. The second series consisted of 3 high "tan", and the third of 3 low "tan".

There were drifting seaweeds such as Sargassum present on the fishing grounds during spring and summer, and the bottom consisted of reefs, gravel, sand and shells. So, it seemed that this area was suitable ground for spawning of fishes. Furthermore, the sea current in this region flows towards north, parallel to the shore on the flood tide and towards south on the ebb.

3 RESULTS AND DISCUSSION

3.1 Swimming direction

Tsukahara, Shiokawa and Inao (1957) have reported on the relation between swimming direction and current along the shore during the night, and stated that 65 percent of the fish caught was gillnetted on the current-ward side of the net and 35 percent on the opposite side.

Note: 1 "Tan" is a Japanese measuring unit for gillnets. One "tan" is 50m long and 2.25m deep, and the mesh size, 43.3mm.

²A high "tan" is 50m long and 2.25m deep. The author used nets of this size in 1955.

³A low "tan" is 50m long and 1.50m deep. Nets of this size were not used in 1955.

TABLE I - Results of experimental fishing in 1955 and 1962

1955	May										July		Aug.
	9	14	16	23	27	4	12	9	20	3			
Duration of fishing	7pm-1am	7pm-5am	7pm-5am	7pm-2am	7-11pm	7pm-5am	7pm-5am	7pm-11am	7pm-11am	7pm-11am			7pm-11am
Water temperature (°C)	19.0	20.4	20.0	20.1	20.5	21.0	22.0	23.5	26.3	27.5			
Catch <u>C. opisthopus hirail</u> in <u>C. heterurus doderleini</u> number <u>C. starksi</u> <u>C. agoo</u>	51 1 0 0	94 5 0 0	64 0 0 0	69 2 0 0	23 7 0 0	138 4 1 0	606 5 6 0	58 2 10 0	27 4 40 0	4 0 17 0			
Total	52	99	64	71	30	143	617	70	71	21			
1955	1962 May										1962 June		
	Sept. 26	7-10pm	24.0	19	22	24	25	30	4	8	19		
Duration of fishing				8pm-4.30am	6.30am-12pm	7-12pm	7.30-9.30pm	7pm-4am	9pm-11.30	7-10pm	7-10pm		
Water temperature (°C)				-	-	19.6	20.8	20.5	20.8	21.0	21.0	Total	
Catch <u>C. opisthopus hirail</u> in <u>C. heterurus doderleini</u> number <u>C. starksi</u> <u>C. agoo</u>	0 0 1 2	1134 30 75 2	315 4 0 0	10 1 0 0	328 2 0 0	79 0 0 0	264 2 0 0	34 1 0 0	116 7 0 0	99 38 2 0	1245 55 2 0		
Total	3	1241	319	11	330	79	266	35	123	139	1302		

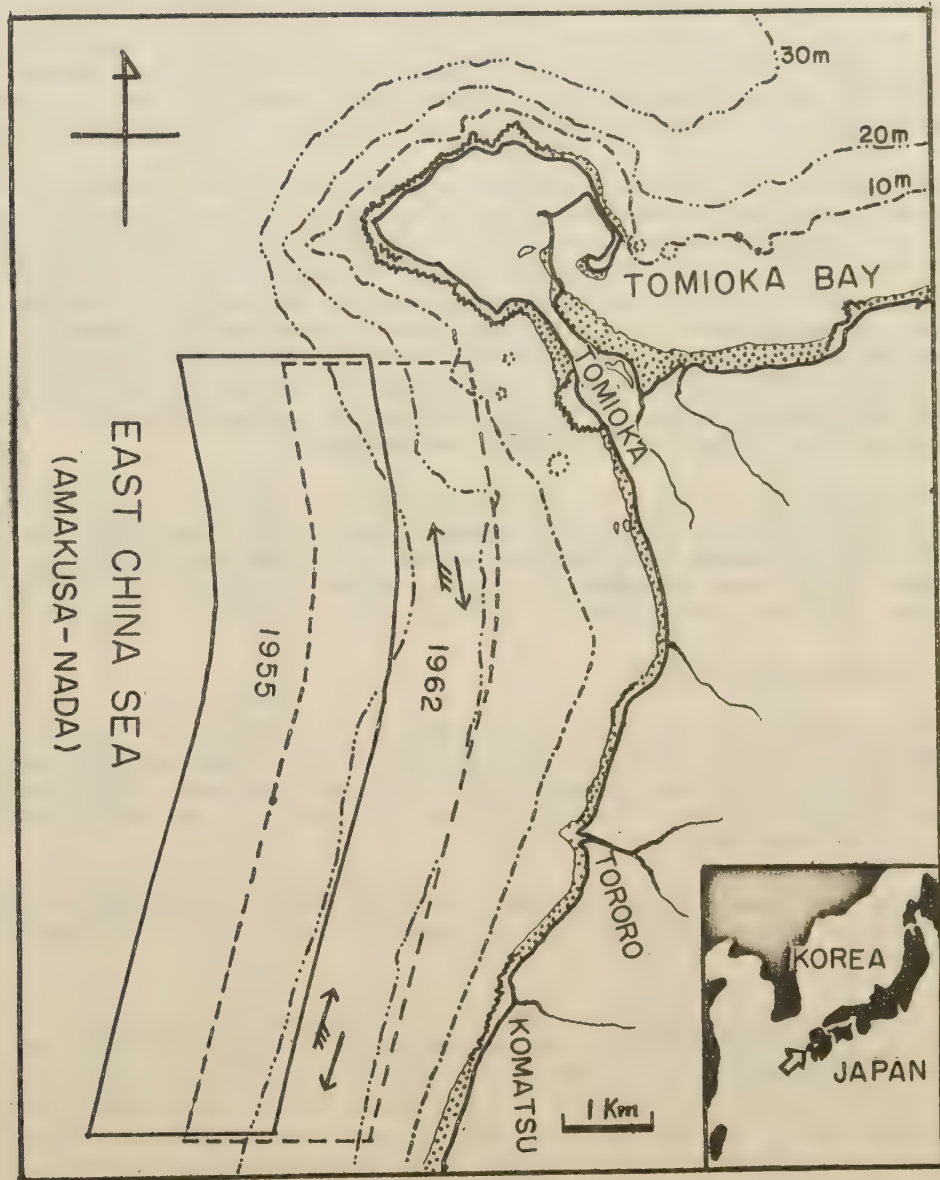


Fig. 1 Map of the fishing ground of the flying fish off Amakusa Islands, Kyushu, Japan, in 1955 and 1962. The area enclosed with a solid line indicates the fishing ground in 1955 and a dotted line, the ground in 1962.

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Besides, it had been mentioned by Kojima (1961) that over 95 percent of the fish caught offshore were gillnetted on the current side of the net as against 78 percent in the coastal region during the daytime. The author believes that flyingfish has a natural habit of swimming in the same direction as the sea current, but in the spawning grounds along the coast the swimming direction of the fish differs from that offshore where the fish do not spawn. He noticed that the fish which migrated shoreward, return to offshore waters after spawning. Whereas in 1955 the net was set at right angles to the current, it was set nearly parallel with sea current in 1962. Table II shows the hourly changes in swimming direction.

The ratio between the fish that were gillnetted while moving towards the shore and those netted while moving offshore was found to be about 7:10 in favour of the latter at 7 to 8pm, 3 or 4:10 at 8 to 10pm and 7:10 at 10 to 11pm and after 11pm about 10:10 or more. However, the final count showed the number of fish that were gillnetted while swimming offshore to be twice as many as the fish moving towards the shore. This phenomenon might be due to the following reason: the fish that have migrated to the coastal waters to spawn, gathered among the seaweeds, rocks and schools from sunset to 11pm, especially between 8 and 10pm. It would therefore seem that the swimming direction of the fish in the coastal waters during the spawning season is greatly influenced by the location of the spawning ground, and the gillnet should be positioned accordingly.

The author could not observe the spawning behaviour itself but from the above findings it may be concluded that most of the fish spawn between 8 and 10pm along the coast of this region. Imai (1959) reported that another species of flyingfish, Cypselurus heterurus döderleinii spawn in the dense seaweeds at 7 to 20m depth between 3 and 8 am on the southern coast of Kyushu, and that after spawning the fish rise to about 3m from the surface.

3.2 Vertical distribution

During the night, the fish were found mostly in the surface layer up to 100cm depth (Tsukahara, Shiokawa and Inao, 1957). Fish swimming at the surface up to 25cm depth accounted for 29 percent of the total, while those between 26 and 50cm depth formed 34 percent and between 51 and 100cm depth were 18 percent. Only 8 percent of the total number of fish occurred at 101 to 150cm depth.

Judging from the report by Kojima (1961) and the hourly changes in the swimming layer during the night, it seems that the fish are found in the layer from surface to 100cm depth in the daytime, too.

3.2.1 Hourly change The number of fish gillnetted during the night and the hourly change in their vertical distribution are shown in Fig.2. Density and movement of fish gradually changed during the night and between 7 and 9pm the fish were found in greatest abundance in the layer from surface to 25cm depth, being only slightly less abundant in the 26 to 50cm layer; but the position changed completely from 9 to 11 pm. From 11 pm to 3 am fish in the 26 to 50cm layer and the 51 to 100cm layer increased in proportion. Between 3 and 5 am the fish were again found in largest proportions in the layer between the surface and 25cm depth.

3.2.2 Seasonal change The flyingfish migrates to the region under study during the spawning season. Based on the data obtained in 1955 and 1962 the number of fish gillnetted between 8 and 11pm is presented in relation to depth in Table III, and in Fig.3. In 1955, the ratio of the fish in the layer between the surface and 50cm depth was about 60 percent of the total at the beginning of the fishing season, but increased gradually until in the peak of the spawning season, from the end of May to the beginning of June, it reached a maximum of about 90 percent. The ratio then gradually decreased to 60 percent by the end of the spawning season. The data for 1962 are incomplete, except for the later part of the spawning season, the curve for which shows very much the same pattern as in 1955. These curves of seasonal variation in occurrence of fish in the upper layers bear similarity to the variations in commercial catch and to the seasonal changes in the gonad index as mentioned in an earlier paper (Shiokawa, 1962). From these observations, it is clear that more fish swim in the upper layer during the earlier half of the night (8-11pm) at the peak of the spawning season than at the beginning or end of the season.

TABLE II - Hourly changes in swimming direction of the flying fish (*Gypselurus opisthopus hirail*)

Date	Swimming direction	Number of fish gillnetted											Total
		7-8 pm	8-9 pm	9-10 pm	10-11 pm	11-12 pm	12pm 1am	1-2 am	2-3 am	3-4 am	4-5 am		
1955 June	4 From offshore	10(0.56)	34(0.79)	3(0.27)	-	-	-	1	4(1.00)	-	7(3.50)	59(0.76)	
	From coast	18	43	11	-	-	-	0	4	-	2	78	
	12 From offshore	-	42(0.88)	98(0.69)	29(0.67)	28(1.40)	46(0.96)	8(0.16)	7(3.50)	-	-	258(0.71)	
	From coast	-	48	43	43	20	48	51	2	-	-	355	
1962 May	19 From offshore	-	10(0.09)	11(0.10)	-	-	-	16(1.60)	-	37(2.64)	-	74(0.30)	
	From coast	-	107	113	-	-	-	10	-	14	-	244	
	24 From offshore	13(0.46)	42(0.26)	17(0.19)	32(3.56)	-	-	-	-	-	-	104(0.36)	
	From coast	28	163	87	9	-	-	-	-	-	-	287	
1962 June	25 From offshore	12(2.00)	33(1.10)	-	-	-	-	-	-	-	-	45(1.25)	
	From coast	6	30	-	-	-	-	-	-	-	-	36	
	30 From offshore	14(0.67)	38(0.56)	12(0.16)	3(0.10)	-	-	-	4(0.57)	3(0.60)	-	74(0.36)	
	From coast	21	68	74	30	-	-	-	7	5	-	205	
1962 June	4 From offshore	-	-	2(0.13)	7(0.70)	-	-	-	-	-	-	9(0.36)	
	From coast	-	-	15	10	-	-	-	-	-	-	25	
	8 From offshore	20(1.33)	21(0.70)	9(0.50)	-	-	-	-	-	-	-	50(0.79)	
	From coast	15	30	18	-	-	-	-	-	-	-	63	
19	From offshore	-	26(1.18)	22(0.63)	-	-	-	-	-	-	-	48(0.84)	
	From coast	-	22	35	-	-	-	-	-	-	-	57	
Total	From offshore	69(0.73)	246(0.48)	174(0.35)	71(0.77)	28(1.40)	46(0.96)	25(0.41)	15(1.15)	40(2.10)	7(3.50)	721(0.53)	
	From coast	88	511	496	92	20	48	61	13	19	2	1350	

Note: The parenthesized figures show the proportion of fish gillnetted on the seaward side of the net in relation to those gilled on the landward side

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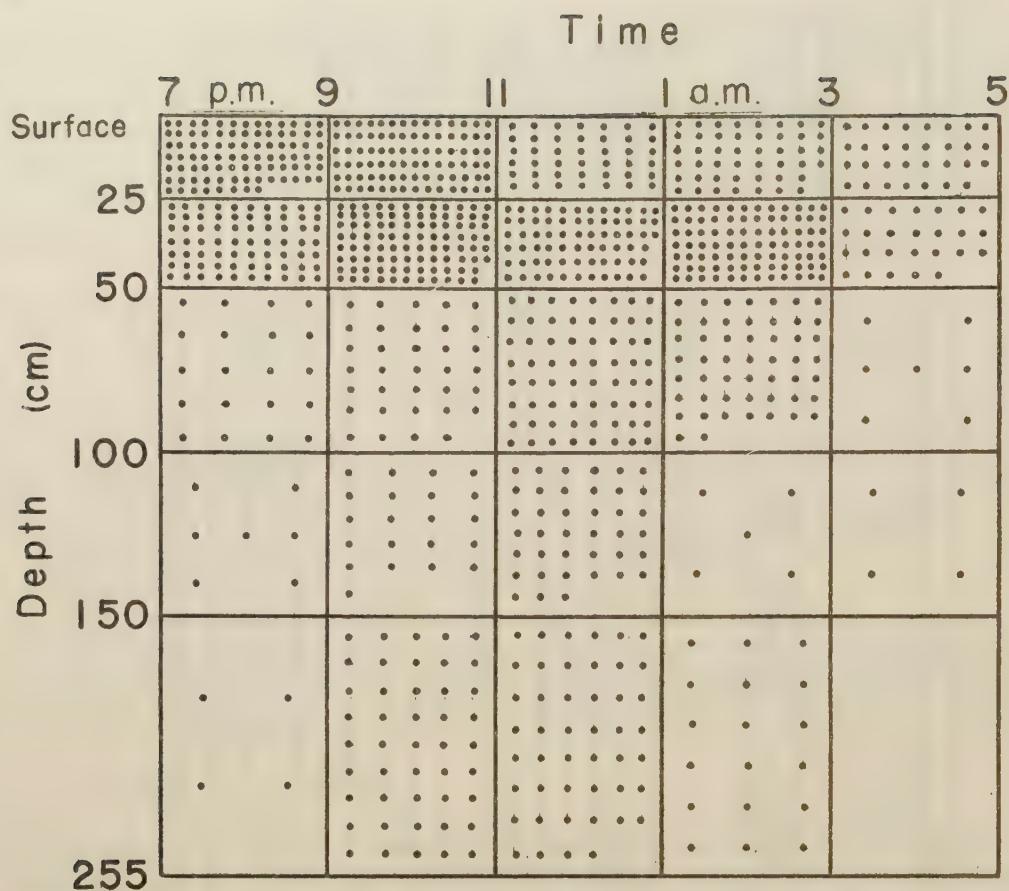


Fig. 2 Hourly change in vertical distribution of flying fish, Cypselurus opisthopus hiraii in the night-time. A dot is shown in permillage. (After H. Tsukahara et al.¹)

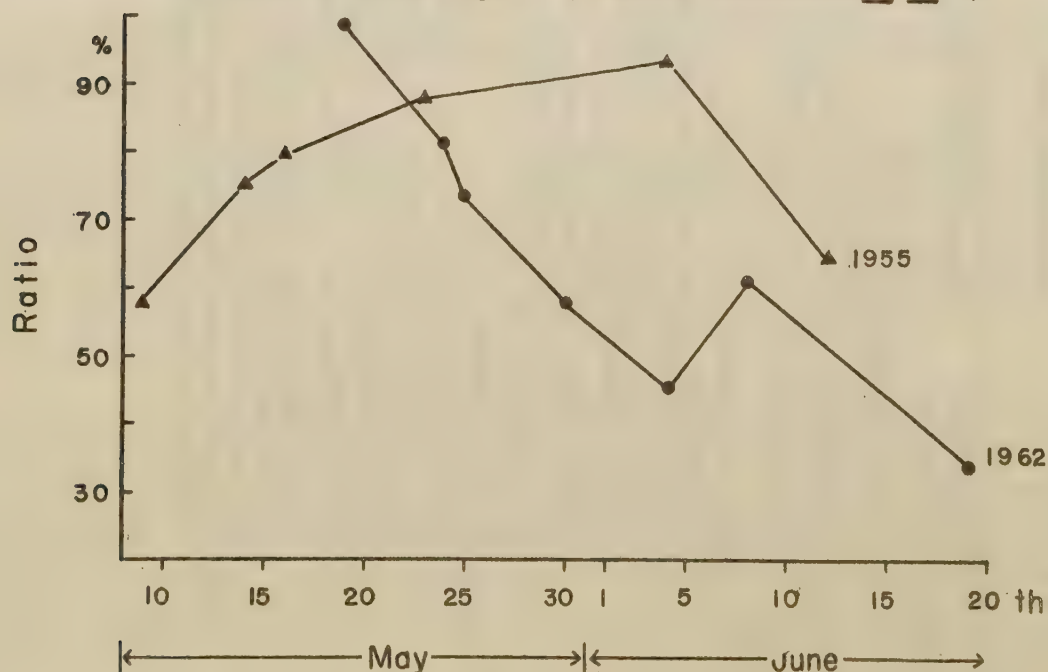


Fig. 3 Seasonal changes of the ratio of the number of fish gillnetted in the layer from surface to 50 cm depth to the total in the night-time, in 1955 and 1962.

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3.3 Horizontal distribution

To understand the density of fish in the upper layer during the spawning season, the number of fish gilled swimming offshore (netted on the landward side of the net) from 7 to 11pm was arranged by day without considering the depth of the swimming layer. The average number, deviation and coefficient of variation (deviation/average number) of the gillnetted fish per hour and "tan" were calculated as shown in Table IV. In this consideration, the author did not utilize the data pertaining to days of poor catches, when the average number of catch per hour and "tan" was less than 2 fish, or the days when the net was not properly set, or the number of fish gillnetted at 150 to 225cm depth layer in the high "tan" net.

It is seen that the average number of fish gillnetted per hour and "tan" was 4 to 18 and its coefficient of variation was 0.5 to 0.8. The days on which the coefficient of variation showed higher values (0.7 to 0.8) were 24 and 30 May, 1962, when the fishing time was one hour longer than that on the other days, resulting presumably, in a change in the movement of fish. If the data for these days were eliminated, the coefficient of variation would be between 0.5 and 0.6.

TABLE IV - Average number deviation and coefficient of variation of the fish gillnetted on the landward side of the net per hour and "tan"

Date	Time pm	Total no. of "tan" of net used	No. of fish gillnetted on landward side of the net	Average no. of fish gillnetted per hour and "tan"	Deviation	Coefficient of variation
1955 June	4 7-10	8	44	5.50	3.33	0.61
	12 8-11	12	187	15.58	7.45	0.48
1962 May	19 8-10	12	219	18.25	11.48	0.63
	24 7-11	24	224	9.33	7.94	0.85
	30 7-11	24	185	7.71	6.12	0.79
1962 June	8 7-10	18	64	3.55	2.05	0.58
	19 7-10	12	57	4.75	2.66	0.56

When the swimming direction of fish was not taken into consideration, the average number of fish gilled per "tan" was found to be 6 to 25, with the coefficient of variation of 0.3 to 0.7. In the upper layers of water, there will not be crowding of fish, no matter how large a number of fish may migrate to this region for spawning.

3.4 Improvement of the gillnet

The results of experimental fishing in 1955 showed that 89 percent of fish were found in the layer between the surface and 150cm depth even during the night. Therefore, if the height of a high "tan" is reduced by about 1/3 and if the part cut off is added to the length, it may be possible to improve the fishing efficiency of the gillnet. With this point in mind, two kinds of nets were prepared for experimental fishing.

In this experimental fishing a series consisting of three high "tan" and three low "tan", connected alternately, was used six times. Also a series consisting of three high "tan" and another consisting of three low "tan" were used independently twice. The result (Table V) showed that the catch of the high "tan" was much larger than that of the low "tan", except on one instance on 4 June. The catches by high "tan" and low "tan" showed a significant difference at a level of confidence higher than 5 percent.

TABLE V - Results of test fishing, using high "tan" and low "tan" nets in 1962

Date	19	22	May 24	25	30	June 4	Sub- total	8	June 19	Sub- total	Total		
Fishing method	A series consisting of 3 high "tan" and 3 low "tan" of net, connected alternately, was used						Sub- total	A series consisting of 3 high "tan" and 3 low "tan" were used independently			Sub- total	Total	
Duration of fishing	8pm- 4.30 am	6.30am - 12pm	7pm - 12am	7.20 - 9.30pm	7pm - 4am	9pm - 11.30		7pm - 10	7pm - 10.30				
Height of net	High low	High low	High low	High low	High low	High low		High low	High low	High low	High low		High low
Depth of capture (cm)													
0-25	150	90	1	23	33	37	288	19	25	13	32	320	254
26-50	49	17	3	8	50	47	179	17	18	12	29	208	177
51-100	5	2	2	10	33	33	78	16	12	25	41	119	79
101-150	1	0	0	1	9	5	17	7	2	6	13	30	17
151-225	1	-	3	0	17	-	23	0	-	18	18	41	-
Total	206	109	6	42	142	122	585	59	57	74	133	718	527

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The high "tan" is 75cm higher than the low "tan". When the number of fish gillnetted in the layer between 150 and 225cm was eliminated, the catches of high and low tans showed no significant difference. It appears, therefore, that there is no significant difference between the two nets in catch per unit area of netting down to 150cm below the surface.

If the height of the high "tan" is reduced to 150cm, the fishermen theoretically can make a new "tan" out of the two pieces cut off. And if the new "tan" is connected as an addition to the net and if this net is used for fishing, the author is sure that more fish would be caught.

It is not known whether the catches of the two "tans" would be affected at the point they are joined together because of the difference in height. Sufficient data could not be obtained to clarify this point, but judging from the result of the test-fishing on 8 and 19 June, it seems that this will not affect the catch.

4 REFERENCES

- Imai, S., Studies on the life histories of the flyingfishes found in the adjacent waters of
1959 Japan. 1 Mem.Fac.Fish.Kagoshima Univ., 7:1-86 (In Japanese with English abstract)
- Kojima, S., Studies on the locomotion behaviour of fishes. 1 On the conditions of flying
1961 fish entangled on the tide ward side or lee tide of the net. Bull.Jap.Soc.scient.Fish., 27(4):313-7 (In Japanese with English abstract)
- Okachi, I., Studies of morphological characteristics and growth of the flyingfish caught in
1958 the Japan Sea. Rep.Japan Sea reg.Fish Res.Lab., (4):15-24 (In Japanese with English abstract)
- Shiokawa, T., Studies on the small coastal gillnet fisheries and their resources(1). On the
1962 flyingfish draft gillnet fishery. Bull.Jap.Soc.scient.Fish., 28(6):574-8 (in Japanese with English abstract)
- Tsukahara, H., T. Shiokawa and T.Inao, Studies on the flyingfishes of the Amakusa Islands.
1957 Part 3-4. The life histories and habits of three species of the genus Cypselurus. Sci.Bull.Fac.Agric.Kyushu Univ., 16(2):287-311 (In Japanese with English abstract)

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DIRECTION OF SETTING THE PURSE SEINE IN
CONSIDERATION OF THE BEHAVIOUR OF ANCHOVY SCHOOLS

by

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Abstract

Decisions taken in the direction of setting an anchovy purse seine were studied from the logbook of KATU MARU (a two-boat purse seiner) operating in Tateyama Bay, Chiba Prefecture, Japan, from June 1951 to May 1952.

Wind and current directions are commonly the important factors in deciding the direction of setting a purse seine, but in Tateyama Bay they are not the most decisive factors. Here the most important consideration is the contour line or gradient direction of the sea bed. It is believed that in the Bay an anchovy school, frightened by the sound of boats or the motion of nets, descends to deeper water. It was found that 80 percent of all operations were made with the mouth facing the shallower depth contours. There is an indication that this consideration of contours is more important for the middle- and large-sized fish than for the smaller ones. The orientation of the net in relation to the direction of the sun near sunrise and sunset is another consideration.

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ORIENTATION DE LA SENNE TOURNANTE EN FONCTION DU COMPORTEMENT DES BANCs D'ANCHOIS

Résumé

L'auteur a étudié, sur la base du journal de bord du KATU MARU (l'un des deux bateaux travaillant en paire), diverses orientations données à une senne tournante à anchois lors de pêches effectuées dans la baie de Tateyama, Préfecture de Chiba (Japon), de juin 1951 à mai 1952.

Si la direction du vent et celle des courants sont généralement les principaux facteurs qui déterminent la direction dans laquelle est posée une senne tournante, ce n'est pas le cas dans la baie de Tateyama, où il faut tenir compte avant tout des courbes de niveau, ou du sens de la pente du fond de la mer. On pense que dans cette baie les bancs d'anchois, effrayés par le bruit des bateaux ou par le mouvement du filet, gagnent des eaux plus profondes. On a constaté que 80 pour 100 des pêches ont été faites avec l'ouverture du filet faisant face aux isobathes des faibles profondeurs. Il semblerait que le rôle joué par les courbes de niveau soit plus important pour les poissons de moyenne et grande taille que pour les petits. On s'est également attaché à l'orientation du filet par rapport à la direction du soleil aux approches de son lever et de son coucher.

DIRECCION DEL LANCE DE UNA RED DE CERCO TENIENDO EN CUENTA EL COMPORTAMIENTO DE LOS CARDUMENES DE ANCHOAS

Extracto

En base al diario de pesca del KATU MARU (un barco perquero con dos botes) que actuó en la Bahía de Tateyama, Prefectura de Chiba, Japón, desde junio de 1951 a mayo de 1952, se estudiaron las decisiones tomadas con respecto a la dirección del lance de una red de cerco para anchoas.

Las direcciones del viento y de las corrientes constituyen por lo general los factores importantes que deciden la dirección del lance de una red de cerco, pero en la Bahía Tateyama no son los más decisivos. En este lugar la consideración más importante es la línea del contorno o la dirección de la inclinación del fondo del mar. Se cree que en la Bahía un cardumen de anchoas asustado por el ruido producido por las embarcaciones o por el movimiento de las redes desciende a aguas más profundas. Se comprobó que el ochenta por ciento de todas las operaciones de hicieron con la boca de la red orientada hacia los contornos más someros. Hay indicios de que esta consideración de los contornos es más importante con respecto a los peces de tamaño medio y grande que con respecto a los más pequeños. Otro extremo que hay que tener en cuenta es la orientación de la red en relación con la dirección del sol hacia la salida y la puesta de éste.

1 INTRODUCTION

Purse seining is done in Japan during day and night. Fishing at night is done with the help of lamps to attract fish. When seining during day the schools of fish are first located by sight or with the aid of fish-finders, and then encircled by the net. A knowledge of the swimming behaviour of fish schools is therefore of great importance in successful daytime seining. Very little is known at present of the environmental factors influencing the swimming course of fish. According to the studies of Gawn and Saunders, which are quoted by Ilmo and Laevastu (1961), fish usually swim against the current, though in weak currents other directions and orientations occur. Marshall (1965) pointed out that in a strong flow neutrally buoyant fish must be able to swim upstream as fast as the current can carry them downstream, if they are to hold a steady position. The nature and direction of current should therefore decide the direction of setting the purse seine, but the school may change its course to unexpected directions immediately before the net is set, and when scared by the sound of the boat's engine or the motion of net in the water. This is one of the main reasons for failure of purse seining operations during day.

The directions in which the schools change their course when scared by external stimuli caused by boats or nets, and the changes in fishing tactics to be therefore adopted for successful daytime purse seining, are considered in this paper.

2 DATA

The source data used in the present paper were obtained from the logbook of a seiner, the KATU MARU, 18 gross tons based at Tateyama, Chiba Prefecture. The fishing was done by the two-boat purse-seining system in daytime. The data analyzed in the present study were collected over one year, from June 1951 to May 1952. Records covered weather, wind, current, catch, fish species caught, and schematic records indicating the direction of the seine just after setting the net. Searching for fish schools was done with the aid of fish-finders. The species of fish caught were the anchovy Engraulis japonica and Trachurus japonicus, Clupanodon thrissa and Sardinops melanosticta. As anchovy formed 90 percent of the total catch, only this fish is considered in the present paper. The average catch of anchovy was about 400 kg per set, throughout the fishing season. The anchovy schools were classified into three fish sizes as follows: small-sized fish of 5 to 8 cm body length; middle-sized fish of 8 to 12 cm; body length, and large-sized fish of over 12 cm body length.

The directions of wind and seine recorded in the logbook were reclassified into eight directions, namely, N, NE, E, SE, S, SW, W, NW and N, and the direction of the seine was shown by the mark U, implying that the two seiners were situated at the open ends of the U after the net was set. Tateyama Bay was divided into nine sections from the configuration of the contour lines as shown in Fig.1.

The directions of setting the seine were recorded in the logbook each month, and plotted on charts but only the data for June and July (the summer season) and December and January (the winter season) are considered in this paper (Fig. 2 and 3 and Table I).

3 DISCUSSION

The factors to be considered when setting purse seines are: the swimming direction of fish schools and the directions of wind and current.

The most desirable setting is when the wind and the current run counter to each other as shown in Fig.4. Then having encircled the school the two seiners have the net to windward. It can be seen in Fig.5 that the seiners do not often set the net so that it finishes to windward of them. Throughout the period of observation the maximum wind speed was 3m/sec and the frequency of occurrence of the wind speed over 2m/sec was only 13 times, which was 8 percent of the total number of operations (162 sets). According

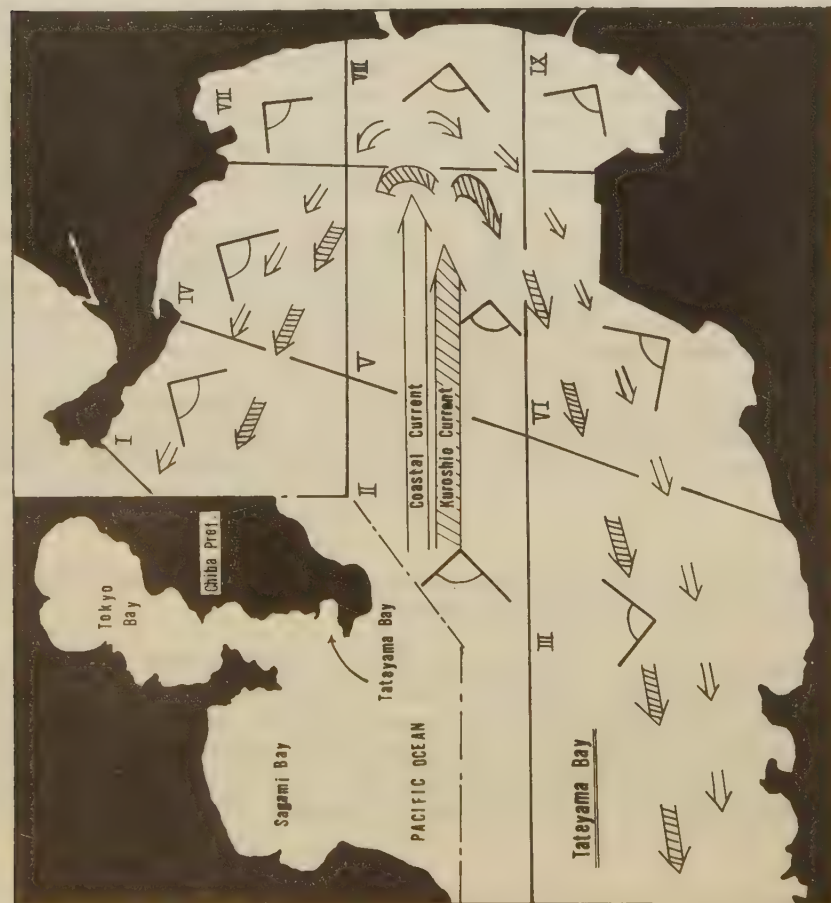


Fig. 1 Schematic presentation of the current in Tateyama Bay. White arrows show the flowing of the coastal current and hatched arrows mark the flowing of the branch of the Kuroshio Current. The angle of 90° shown in the different sections indicate the gradient of sea bottom in each section.



Fig. 2 The direction of seine - June and July 1951. Arrows and the figures beside them show the direction of wind and its speed (m/sec). The figures beside the U show the number of the observation as given in Table I.



Fig. 3 The direction of seine - December 1951 and January 1952

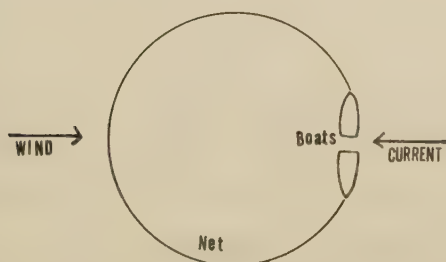


Fig. 4 Typical position of two-boat purse seines in regard to wind and current after setting

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TABLE I - Records of the operations shown in
Fig. 1 and 2

No.	June, July Fig. 1					No.	Dec., Jan. Fig. 2				
	Date	Time	Weather	Size of fish	Catch		Date	Time	Weather	Size of fish	Catch
1	June 17	15.40	c	S	P	1	Dec. 30	14.15	c	S	Nil
2	17	14.15	b	S	P	2	19	16.10	b	L	Nil
3	24	10.45	b	S	P	3	19	13.25	b	L	E
4	26	10.15	b	M	E	4	17	17.00	b	M	E
5	26	11.30	b	M	G	5	19	8.05	b	L	E
6	14	8.30	c	S	Nil	6	19	13.25	b	L	E
7	19	10.50	b	S	G	7	19	10.15	b	L	E
8	22	7.15	b	S	E	8	20	16.15	c	S	G
9	24	15.20	b	S	G	9	17	15.25	b	M	E
10	17	16.50	b	S	G	10	25	8.05	c	S	P
11	22	15.00	b	S	Nil	11	17	14.15	b	M	E
12	14	6.05	b	S	G	12	13	8.10	c	M	G
13	13	13.10	b	S	G	13	13	10.10	c	M	G
14	30	12.00	r	M	E	14	21	8.00	c	M	G
15	20	17.05	r	S	G	15	9	17.10	b	S	P
16	30	13.30	r	S	G	16	12	15.50	c	S	E
17	13	14.40	b	S	G	17	12	17.50	c	S	G
18	24	12.15	b	S	Nil	18	12	13.35	c	S	E
19	24	13.30	b	S	E	19	20	18.15	b	S	E
20	22	12.25	b	S	G	20	12	11.50	b	S	Nil
21	22	16.25	b	S	G	21	27	14.40	b	S	G
22	22	16.25	b	S	P	22	26	13.50	b		E
23	22	11.00	b	S	E	23	26	14.50	b		E
24	22	9.50	b	S	E	24	26	16.40	b		E
25	22	8.25	b	S	E	25	27	13.20	b		E
26	30	15.40	r	S	G	26	28	8.25	b		E
27	24	6.15	b	S	P	27	Jan. 10	8.00	b	S	P
28	26		b	M	G	28	27	17.20	b		E
29	July 30	11.15	c	—	—	29	5	11.30	b	S	G
30	17	9.15	c	M	P	30	5	12.20	b	S	G
31	17	19.30	c	M	E	31	27	14.45	b	S	G
32	17	6.10	c	M	E	32	24	11.20	c		E
33	17	7.30	?	M	E	33	24	12.40	c	M	G
34	7	6.45		L	E	34	26	15.10	c	M	G
35	7	17.45	c	M	E	35	14	8.35	c	S	Nil
36	10	8.15	b	S	G	36	10	9.20	b	S	G
						37	26	9.15	b	S	Nil
						38	29	8.15	b	S	Nil
						39	24	8.50	c	M	E
						40	24	13.50	c	M	G

Time: starting period of setting seine
Weather: b—blue sky; c—cloud; r—rain
Size of fish: S—small; M—middle; L—large
Catch: P—poor (less than 400 kg);
G—good (400–1,000 kg);
E—excellent (over than 1,000 kg)

to the fishermen, purse-seining operations are not much influenced by wind speeds below 2m/sec, it was not often necessary to consider the effect of wind.

The form of the net when set against the current must be considered from two points of view: one is biological, the effect of current on the swimming direction of fish, and the other is the hydro-dynamical effect on the operation itself, as the form of the net is often transformed during the fishing operation by the current. These two aspects are usually counter-directed, because the desirable setting of the seine is with the current flowing into the seine which means that the fish if they do have an orientation to the current will commonly be heading out of the seine. According to the fishermen, no special attention need be paid, in slow current, to the relation between the current and the direction of set, while in a swift current fishing ought to be given up. The directions of setting the seine and prevailing currents, are indicated respectively in Fig. 1 and 5. Detailed observations on the currents in Tateyama Bay are not available, but according to the data recorded at the Tateyama Fisheries Experimental Station and in the logbook of the KATU MARU, there are two different streams of current as shown in Fig. 1: the first is the coastal current running from Sagami Bay, and the other a branch of the Kuroshio current. The former flows into Tateyama Bay all the year round, but the latter flows only in summer. Both these streams run into the bay from the West, each dividing into two at the centre of the bay as shown in Fig. 1, with one branch running counter-clockwise along the shore towards the north and the other running clockwise along the shore towards the south. Their speeds are usually below one knot. Tidal currents and currents arising from river outflow are not considered because of their lower speeds.

According to the fishermen operating in Tateyama Bay, the most important factor to be considered when operating the seine is the direction of gradient of the bottom. This finding is based on data obtained from records of fish-finders and the observations of fishermen on the behaviour of the fish, namely, that the schools of anchovy near the surface descend immediately to the bottom when a motor boat approaches them as seen in fish-finder traces, and take shelter in deeper areas of the sea (there is, however, no record in evidence of their movement to deeper water). It is seen in Fig. 2 and 3 that a large number of sets face the shallower part of the sea; this is because the nets are mostly set with a view to cutting the retreat of scared schools. The directions of gradient are different in each section as shown in Fig. 2 by contour lines, and in Fig. 1 by right angles facing toward shallower water. In each section, the ratio of the number of sets facing the shallower depth contour (n) to the total number of sets (N) are shown as a fraction in Table II. From the results it was confirmed that the direction of setting purse seines in Tateyama Bay was dependent to a very considerable extent (80% of the total, see Table II) on the direction of gradient of the bottom.

The values of n/N varied in different sections and with sizes of fish. The n/N values in Sections I, II and III were larger than in the others. The values for the middle- and large-sized fish were also larger than for the small ones.

From the above observations the authors drew the following conclusions:

- (a) that the tendency for the schools to swim down into deeper water, when scared by engine noise or the motion of net, increases as the angle of gradient of the bottom increases. (The bottom of sections I, II and III is far more steep than of the others), and/or
- (b) that this tendency is more pronounced in the middle- and large-sized fish than in the small ones. As the bigger fish occur in the deeper water where the gradients are steeper it is difficult to know on which to place emphasis. The bigger fish could in any case swim to the deeper waters faster.

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Analysis of the data in Tables II and III further strengthen the above conclusions. Section V, the centre part of Tateyama Bay, is the most valuable fishing area and fish of various sizes have appeared in it as shown in Table II. In this section, the value of n/N for the middle- and large-sized fish was far greater than for the small-sized fish. It is seen from Table III that the catch exceeded 1,000kg in 36 of the sets out of a total of 162 sets, whereas 22 sets yielded no catch. The average catch per set was about 400kg. The success of the operation does not always depend on the direction of setting the purse seine, because if the school of fish is very large, even with faulty tactics it may still be possible to catch over 1,000kg. In 17 of these 22 unsuccessful sets the seines faced up the slope, with the object of catching the small-sized fish in the coastal area of sections VI to IX. From the results obtained it is clear that for small-sized fish the direction of seine is not so important, whereas, for success in catching middle- and large-sized fish on the deeper slopes the seine should face up the slope of the sea bed.

TABLE II - Number and slope direction of sets for catching different sizes of anchovy in 9 sections in Tateyama Bay

Section	Size of fish	Large n/N	Middle n/N	Small n/N	Unknown n/N	Total n/N
I		8/10	5/5	7/9	2/2	22/26
II		6/6	4/4			10/10
III		3/3	3/3	3/3		9/9
IV			2/3	7/8	6/6	15/17
V		2/2	18/18	29/42	3/3	52/65
VI				8/12		8/12
VII				1/1		1/1
VIII				8/14		8/14
IX				5/8		5/8
Total		19/21	30/31	70/99	11/11	130/162

Note: n = number of sets made with net facing up the slope

N = total number of sets

It is seen from Table II that 32 sets (20% of the total number) were made with the seine facing down the slope; but they were made in consideration of another factor, the position of the sun. According to the fishermen, during a very short period after sunrise and sunset anchovy schools rush towards the sun. This period was arbitrarily taken as 30 minutes after sunrise (Table IV). The data pertaining to sunset were not considered as the direction of the seine is affected more by the gradient of the bottom in Sections II and V, where the sets were done at dusk. The operation was affected by the pursuit of predators (shark and yellow-tail), only twice, in Section I.

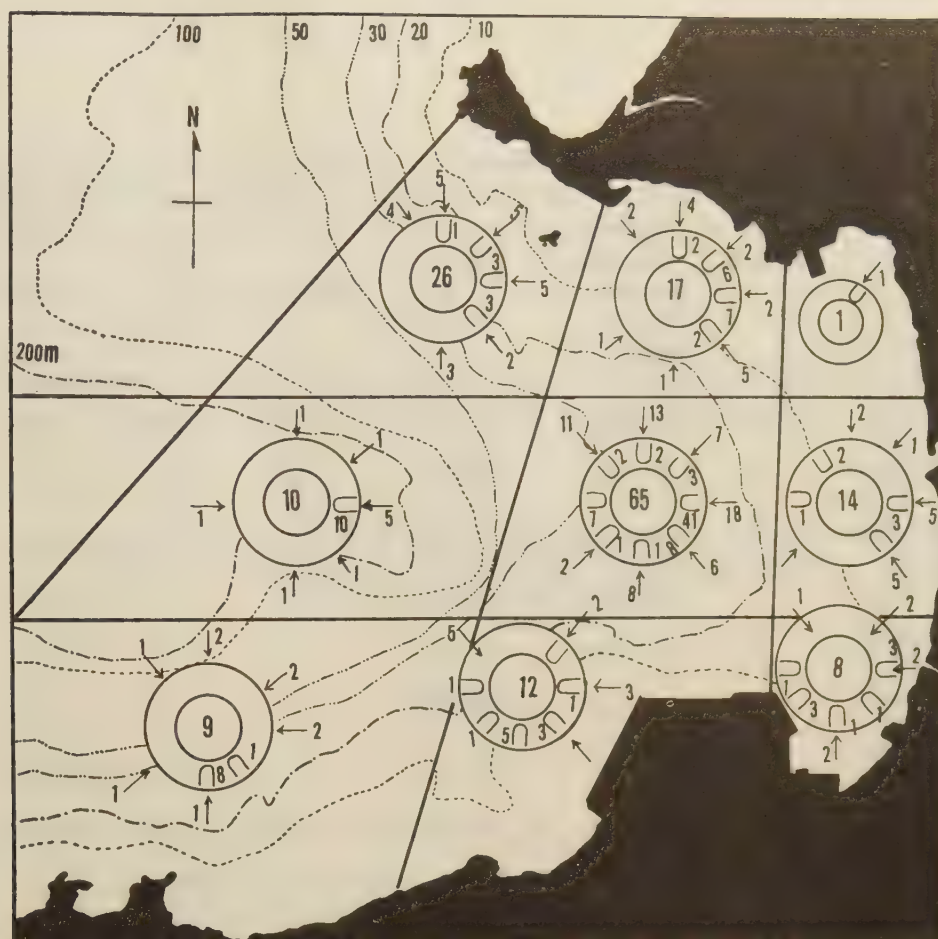


Fig. 5 Relation between the direction of seine and wind. Figures in the centre circle show the total number of operations in each section, and those at the opening of the U indicate the number of operations in each direction. Figures beside the arrows show the frequency of occurrence of wind.

TABLE III - The numbers of successful and unsuccessful sets

<u>Successful sets</u> (catch 1,000 kg)	
Number of successful sets	36
seine facing up the depth contour	31
seine facing down the depth contour	5
Seine facing up the depth contour	31
for catching middle- and large-sized fish	21
for catching small-sized fish	10
<u>Unsuccessful sets</u> (catch nil)	
Number of unsuccessful sets	22
seine facing up the depth contour	17
seine facing down the depth contour	5
Seine facing up the depth contour	17
for catching middle- and large-sized fish	0
for catching small-sized fish	17

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TABLE IV - Records of sets where the direction of seine was set according to the sun (within 30 minutes after sunrise)

Date	Weather	Starting period of the operation	Period of sunrise	Section	Size of fish	catch	Direction of seine
June 17 1951	clear	5h 05m	4h 38m	IX	middle	good	E
Aug. 27 1951	"	5h 35m	5h 09m	IX	small	nil	E
Aug. 29 1951	"	5h 20m	5h 11m	V	"	good	SE
Sept. 3 1951	"	5h 30m	5h 15m	IX	"	poor	NE
Sept. 4 1951	"	5h 45m	5h 16m	V	"	good	E
Sept. 5 1951	"	5h 35m	5h 16m	V	"	good	SE
" 10 1951	"	5h 45m	5h 19m	IX	"	poor	SE
" 29 1951	"	5h 20m	5h 34m	VIII	"	good	NE

Note: Direction of seine SE means opening from the SE as per a SE wind

4 CONCLUSION

In the purse-seine operations in Tateyama Bay the direction of gradient of the bottom is a very important factor in deciding the right direction of setting the net, and 80 percent of the total operations were carried out with the net facing up the slope of the contour lines, but this is of less importance for the smaller fish caught in the shallower and less sloping areas.

It seems that a scared school of anchovy goes down the slope towards deeper water. It also appears that middle- and large-sized fish are more sensitive to external stimuli such as the sound of boat engines or the motion of nets than the smaller-sized fish.

There is need for more technical and biological investigation of the points.

5 REFERENCES

- Hela, I. and T. Leavastu, Fisheries hydrography. London, Fishing News (Books) Ltd., 1961 137 p.
- Marshall, N.B., The life of fishes. London, Weidenfield and Nicolson, 402 p. 1965

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Acknowledgement

The authors express their sincere thanks to Mr. Katutaro Suzuki, the owner of the seiner, KATU MARU, for providing the valuable data for this study.

A RAKE TRAWL DESIGNED FOR CATCHING YOUNG SOLES

by

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Abstract

A beam trawl provided with a rake has been constructed in order to catch young soles for abundance estimates. When the gear operates, the teeth of the rake "plough" the bottom and bring up flatfishes buried in the sand. Comparative fishing experiments indicate that the rake trawl used by day catches about seven times as many soles and plaice per m² as the otter board trawl, which in Denmark is normally used for small flatfishes.

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CHALUT "A RATEAU" POUR LA CAPTURE DES JEUNES SOLES

Résumé

On a construit un chalut à perche dentelée pour capturer de jeunes soles aux fins d'estimation de l'abondance. Lorsque l'engin est en marche, les dents du râteau "labourent" le fond et font sortir les poissons plats enfouis dans le sable. Sur la base de pêches comparatives, le chalut "à râteau", employé de jour, permet de capturer environ sept fois plus de soles et de plies par mètre carré que le chalut à panneaux, normalement utilisé au Danemark pour la capture des petits poissons plats.

RED DE ARRASTRE PROVISTA DE RASTRILLO PARA CAPTURAR
LENGUADOS JOVENESExtracto

Con objeto de capturar lenguados jóvenes para efectuar estimaciones de su abundancia se ha construido una red de arrastre de vara dotada de un rastrillo. Cuando el arte funciona, los dientes del rastrillo "aran" el fondo y hacen salir a los peces planos enterrados en la arena. Los experimentos de pesca comparativa indican que la red de arrastre con rastrillo utilizada de día captura alrededor de siete veces más lenguados y sollas por m² que la red de arrastre de puertas que normalmente se usa en Dinamarca para los peces planos pequeños.

1 INTRODUCTION

In order to obtain reliable estimates of the abundance of small soles on the nursery grounds a new type of trawl has been constructed designed for catching soles that are buried in the bottom.

Soles dig themselves in during daytime, and generally they do not react to a ground rope of a trawl drawn along the bottom by swimming away - on the contrary, they stick to the sand, and are very difficult to catch. During night they usually lie on the bottom or swim around in search for food and can be caught. As a consequence of this behaviour there are huge differences in catch per hour between night and day in the commercial fishery (Kruuk, 1963).

2 SHORT DESCRIPTION OF THE RAKE TRAWL

The photographs (Fig. 1 and 2) show the rake trawl from different angles. It is a gear constructed according to the same principles as the normal beam trawl used in the commercial sole fishery. The frontal opening is 1 m horizontally, the net is 4 m long and provided with a flapper 135 cm from the groundrope. The total meshsize in the net is 5 mm. The groundrope, which is a grass rope with an iron chain, is approximately 115 cm long.

From an iron bar placed in the opening 25 interchangeable spring steel teeth penetrate about 3 cm into the bottom in front of the ground rope. The iron bar is bolted to the frame and is detachable. The frame is composed of iron tubes, which are sand-blasted and spray-zinc-plated. The runners are provided with oak skis in order to ensure that the trawl can be used on soft bottom.

3 COMPARATIVE FISHING EXPERIMENTS

In order to investigate the efficiency of the rake trawl it was compared with a small otter trawl (groundrope length 7 m) a type of gear which for many years has been used to catch young plaice in the Danish coastal waters to obtain estimates of the individual year class strength of 0- and I-group plaice (Ursin, 1958).

The two gears were compared in a series of 18 hauls made from two ships sailing parallel to each other. The fishing was carried out in daylight and took place on a clean, flat, sand bottom at about 2 m depth.

The number of soles (predominantly between 12 and 20 cm) caught per m² in the otter trawl in percentages of the number caught in the rake trawl was 13 with a 99 percent confidence interval of 24 - 2.

The effect of the rake was investigated in a series of 44 hauls where the trawl was used alternately with the rake on, and without rake as an ordinary beam trawl. The catch of soles in the beam trawl in percent of the rake trawl catch was 51 with a 99 percent confidence interval of 76-26.

The corresponding figures for small plaice were: Total catch in otter trawl in percentage of rake trawl: 16, and total catch in beam trawl in percentage of rake trawl: 38.

It is quite obvious that the rake trawl used during daytime is far more effective than the otter trawl and the beam trawl, for sole as well as for plaice. It has not yet been established whether the catches give an estimate of the true abundance of these species, however, observations of the trawl in action indicated that no fish escaped by swimming away from the trawl.

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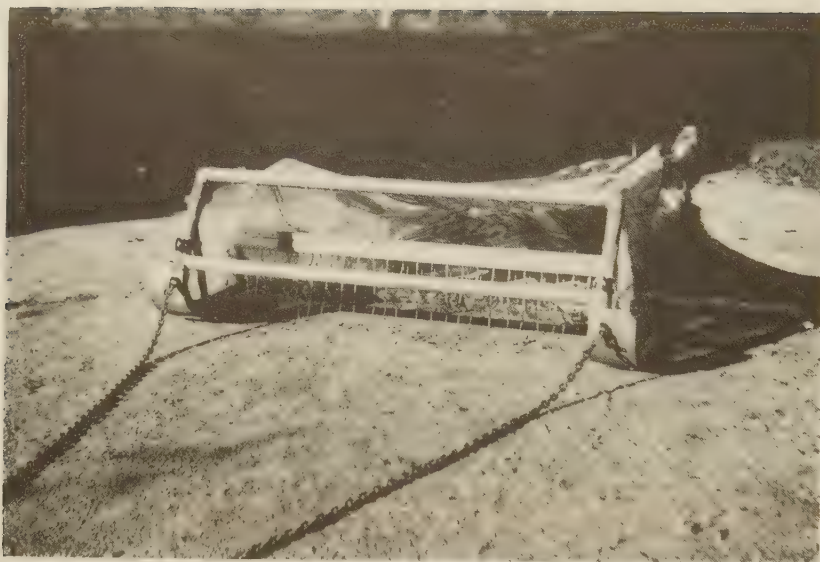


Fig. 1 Rake trawl seen from the front

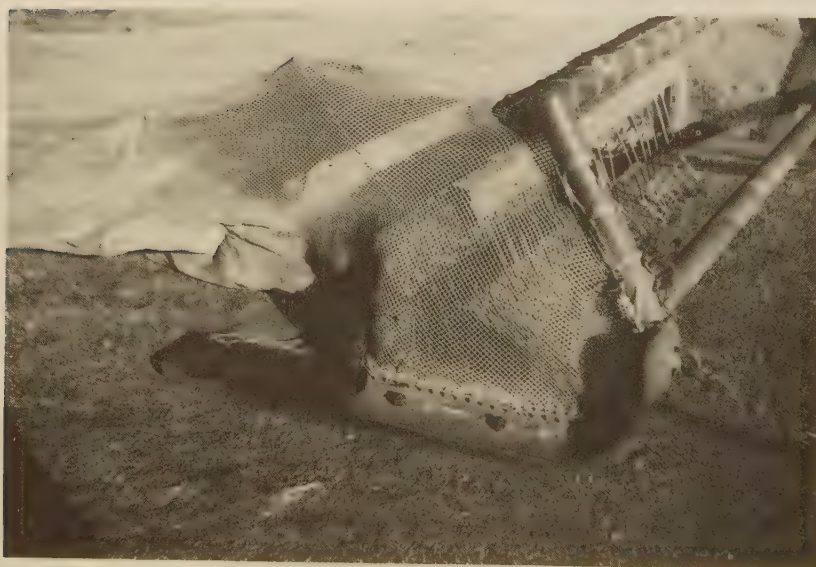


Fig. 2 Rake trawl seen from the side

The teeth of the rake were arranged with 4 cm intervals in order to ensure that all flatfish which measured more than 4 cm from the dorsal to the anal fin, corresponding to about 10 cm fishlength, and which stayed within the upper 3 cm of the sand were hit by the teeth and forced to move, though not necessarily out of the sand.

4 OBSERVATIONS OF THE TRAWL IN ACTION

During several hauls the trawl was observed from a boat drawn after the ship. In average about 15 soles and the same number of plaice were caught in each haul of 10 minutes duration. However, no soles at all were seen swimming in front of the trawl, and none were seen trying to escape over the net. Only a few times a single plaice was observed in front of the trawl, while dozens of gobies were seen escaping.

During the time when the experiments took place no fish at all could be seen on the bottom, neither from the surface nor by a closer investigation of the bottom by a skin-diver. Thus the trawl actually dug up all the flatfishes that were caught.

The reaction of 30 soles to the teeth of the rake was investigated in an enclosure, 40 cm deep. The soles dug into the sand immediately after they were released. A rake trawl, where the net had been removed in order to allow direct observation of the rake, was hauled over the bottom and the reaction of the soles was observed. Unfortunately the greater part of the fish dug in so close to the fence that they could not be caught, but the few of them which stayed in the middle of the enclosure all reacted to the teeth in the same way. When the teeth hit them, they were seen leaving the sand, some in a more or less lazy manner, others jumping out, all of them drifting in between the teeth or closely over the horizontal iron bar, as the gear moved forward. After a few seconds they seemed to have recovered and dug in behind the gear, which by now had moved to a position where the net would have caught the soles, if it had been used.

Only a few times during more than 100 hauls made on soft, sandy as well as on hard bottom were soles found spiked or damaged by the teeth.

5 FUTURE EXPERIMENTS

Compared with an otter trawl and a beam trawl, the rake trawl has proved to be far more efficient for catching young sole and plaice during daytime. The trawl was constructed with the intention of making a gear by means of which the true abundance of flatfishes per m² could be obtained. This quality has not yet been confirmed. However, a tagging experiment has been planned in order to get an estimate of the number of flatfish which are caught, compared with the actual number of fish present in the fished area. In the near future a rake trawl with some modifications will be used on the fishing grounds for comparison with the commercial trawls.

6 REFERENCES

- Kruuk, H., Diurnal periodicity in the activity of the common sole, Solea vulgaris
1963 Quensel. Neth.J.Sea Res., 2(1):1-28
- Ursin, E., The strength of individual yearclasses of plaice in the Danish Waddensea.
1958 Meddr Danm.Fisk.-og Havunders., 2(20):1-14

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RESPONSE OF SKIPJACK TUNA (*Katsuwonus pelamis*)
TO EXPERIMENTAL CHANGES IN POLE-AND-LINE FISHING OPERATIONS

by

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Abstract

Fishermen of Hawaii catch skipjack tuna commercially by pole and line. The fish are chummed with live bait. In this study, the standard techniques were varied experimentally. The usual bait, live anchovy (*Stolephorus purpureus*), was alternated with dead anchovy and tilapia (*Tilapia mossambica*); the water sprays used routinely by commercial fishermen were turned on and off. The response of the skipjack tuna was measured in three ways - by catch rate, the rate of attacks by the tuna on bait, and the numbers of tuna attracted to the fishing ship. By all three measures, skipjack tuna responded better to live anchovy than to dead anchovy and to anchovy better than to tilapia. Water sprays improved the catch rate but not the rate of attack or the number of fish at the ship. The effectiveness of water sprays appeared to depend on the species used as bait.

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REACTION DE LA BONITE A VENTRE RAYE (Katsuwonus pelamis)
AUX MODIFICATIONS EXPERIMENTALES APPORTEES AUX OPERATIONS
DE PECHE A LA CANNE ET A L'HAMECON

Résumé

A Hawaii, la pêche commerciale de la bonite à ventre rayé s'effectue à la canne et à l'hameçon, le poisson étant amorcé à l'appât vivant. Au cours de l'étude, on a modifié expérimentalement les techniques normales, faisant alterner l'emploi de l'appât habituel - anchois (Stolephorus purpureus) vivant - et celui de l'anchois mort et du tilapie (Tilapia mossambica), et fermant et ouvrant les dispositifs d'arrosage communément utilisés. On a mesuré de trois façons la réaction de la bonite: taux de prises, taux d'attaques sur l'appât, et nombre de bonites attirées vers le bateau de pêche. Sur la base des trois critères, la bonite à ventre rayé a mieux réagi à l'anchois vivant qu'à l'anchois mort, et mieux à l'anchois qu'au tilapie. L'arrosage améliore le taux de prises mais non le taux d'attaques ou le nombre de poissons attirés. Il semble que l'efficacité de l'arrosage dépende de l'espèce utilisée comme appât.

REACCION DEL BARRILETE O ATUN LISTADO (Katsuwonus pelamis)
A LOS CAMBIOS EXPERIMENTALES EN LAS OPERACIONES PESQUERAS
CON SEDAL Y ANZUELO

Extracto

Los pescadores de Hawaii pescan comercialmente el atún con sedal y anzuelo. Los peces se atraen con cebo vivo. En este estudio se variaron experimentalmente las técnicas normales. El cebo corriente, la anchoa viva (Stolephorus purpureus), se alternó con anchoa muerta y tilapia (Tilapia mossambica); las aspersiones de agua que suelen hacer los pescadores comerciales se aplicaron y se interrumpieron. La reacción del barrilete se midió de tres modos: por el volumen de las capturas, la proporción de los ataques de los atunes al cebo, y el número de atunes atraídos al barco pesquero. En estas tres mediciones, los barriletes reaccionaron mejor a la anchoa viva que a la muerta, y a la anchoa mejor que a la tilapia. Las aspersiones de agua mejoraron el volumen de captura pero no la proporción de los ataques o el número de peces que se acercaban al barco. La eficacia de las aspersiones de agua parece depender de las especies que se emplean como cebo.

1 INTRODUCTION

Skipjack tuna (Katsuwonus pelamis) are caught in commercial quantities in Hawaii only by use of pole and line and live bait. Each fish is caught individually and much time must be spent in finding, catching, and holding live bait. Attempts to substitute other methods, such as the purse seine (Murphy and Niska, 1953) and gill nets (Matsumoto, 1952; and Shomura, 1963), have been unsuccessful. Efforts at increasing catch, therefore, have been aimed at improving the pole and line method itself. One of the approaches was to study the responses of skipjack tuna to experimental changes during fishing operations. This report describes experiments which compared the catch rate, the attack rate of skipjack tuna on bait, and the concentration of skipjack tuna at the stern of the ship when (i) live and dead anchovies (Stoplephorus purpureus) were used as chum alternately, (ii) water sprays were turned on and off, and (iii) live anchovies and live tilapia (Tilapia mossambica) were used as chum alternately.

2 PROCEDURES

The experiments were performed near the Hawaiian Islands and the Line Islands from the CHARLES H. GILBERT, research ship of the U.S. Bureau of Commercial Fisheries Biological Laboratory, Honolulu. Twenty schools of skipjack tuna were fished during 1958-62. Each experiment consisted of fishing a school for alternate periods under control conditions and test conditions. This design was chosen because the wide range of catch rates among schools (Yuen, 1959) made it desirable to have comparisons within rather than among schools.

Fishing procedures during control periods were similar to those used in the commercial fishery for skipjack tuna (June, 1951). Schools of tuna were located by searching for bird flocks. When a flock was sighted, the ship crossed in front of the school. At the time of crossing, the ship was slowed to about 2 kn and live bait was tossed overboard to create a thin trail of bait to the vessel. If there were indications that the fish had encountered the bait, several pounds of bait were thrown at once to "stop" the school. If this manoeuvre (colloquially known as a "pass") was successful, the school was fished. If the pass was unsuccessful, either another was made or another school was sought.

The fishermen fished from the stern of the ship. Each used a stout bamboo pole with a line and a barbless hook. The hooks, camouflaged with feathers and a skirt of soft plastic or with the plastic skirt alone, were dangled within a few centimeters below the surface of the water. Water sprays were directed on the surface above the hooks. Live bait was broadcast near the hooks to keep the school near the ship.

During the test periods, which were alternated with the control periods, only one aspect of the control procedure was changed at any one time. Furthermore, only one variable was tested on any one school.

In tests of the effectiveness of fishing with dead anchovy or without water sprays, control and test periods were alternated whenever sufficient observations had been obtained from each period. Later, when live tilapia was being compared with live anchovy as bait, each species was used as chum for approximately 2-min periods.

Data were collected to estimate three measures of skipjack tuna response: catch rate, attack rate on bait, and the concentration of tuna at the stern of the ship. To evaluate catch rates, the time at which each fish was caught and the number of hooks in the water at all times were recorded on a voice recorder or a multichannel event recorder. Underwater motion pictures of the tuna provided the data for attack rates and the concentration of tuna at the ship. Colour film (ASA 32) was used, at 24 frames per second, in a 16-mm camera. The pictures were taken from a cylindrical metal tube attached to the port side of the ship (Strasburg and Yuen, 1960) during the experiments with dead anchovy and no sprays. The tube was 7-10 m forward of the fishing area. During the experiments with tilapia, the photography was from an observation room within the ship, 3-6 m inboard of the fishing area (Strasburg and Yuen, 1960). The camera was always held firmly against the windowpane, so that it remained stationary relative to the ship.

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Two procedures were eventually used to estimate the concentration of skipjack tuna at the ship from the film sequences. One method was to count under a dissecting microscope the number of tuna visible in each 24th frame of the film sequence. The total number of fish thus counted, divided by the number of frames examined, provided an estimate of the average number of fish per frame for the sequence. The second procedure involved counting the number of frames occupied by each fish in the sequence as it passed through the picture. The counting was done by projecting the film at slow speed through a reversible projector with a frame counter. When the snout of a skipjack tuna appeared on the screen the frame counter was actuated. This fish was followed until its snout left the screen, when the counter was stopped. The film was reversed and the procedure repeated for each fish that appeared in the sequence. The total number of "fish-frames" in a sequence was then divided by the number of frames in that sequence to obtain the average number of fish present. The first procedure provided an estimate of the fish concentration whereas the second provided the actual concentration. Estimates of concentration from one observation post were not comparable with those from the other, because the posts differed in distance and aspect to the fishing area.

The number of feeding attacks was counted for each film sequence. A feeding attack was characterized by a sudden increase in swimming speed, a change in direction, or both, followed by a snapping movement of the mouth and a deceleration. The numbers were converted to rates - the number of feeding attacks per fish per second - to make sequence-to-sequence comparisons possible.

Each measure of response was treated separately in the statistical analyses. Data from each test period were paired with those from the immediately preceding and succeeding control periods, unless the test period was the first or last in the sequence; then, of course, data were available from only one adjacent control period. The sign test (Siegel, 1956) was applied to the pairs to test the null hypothesis against the alternative hypothesis that the responses of skipjack tuna under control conditions of fishing were greater than their responses under test conditions. The probabilities obtained, however, are approximations because the comparisons were not wholly independent.

3 RESPONSES TO LIVE AND DEAD ANCHOVIES

Anchovies for bait were caught with seines from schools close to shore. Several sets of the seine were usually required to collect enough anchovies for fishing. To minimize any difference between the live and dead anchovies during the experiments, some of the fish from each set were taken for dead bait to be matched with live bait from the same set in the experimental fishing. The dead anchovies were frozen for storage, but thoroughly thawed before use.

Live anchovy was the bait used on all passes at schools, as experience had shown that dead bait would not attract schools to the ship.

Responses of skipjack tuna to live and dead anchovy during four tests are shown in Fig. 1. Data on feeding attacks and number of fish per frame are lacking from three experiments because of poor photographic conditions. Live anchovies were more effective than dead ones; they stimulated a greater catch rate ($p = 0.026$, $n = 22$), and stimulated more feeding attacks ($p = 0.035$, $n = 8$) and concentrated more tuna at the ship ($p = 0.035$, $n = 8$).

That more skipjack tuna were caught with live than with dead anchovies was no surprise. As Tester, Yuen, and Takata (1954) pointed out, pole-and-line fishing for skipjack tuna relies on live rather than dead bait. They also observed that skipjack tuna reacting to dead bait "exhibited continuing feeding activity for a time, but followed the dead fish down as they sank" so that one would expect more skipjack tuna to be concentrated at the ship with live than with dead anchovies. From this observation, however, one would not foresee that live bait would stimulate a higher rate of feeding attacks than dead bait.

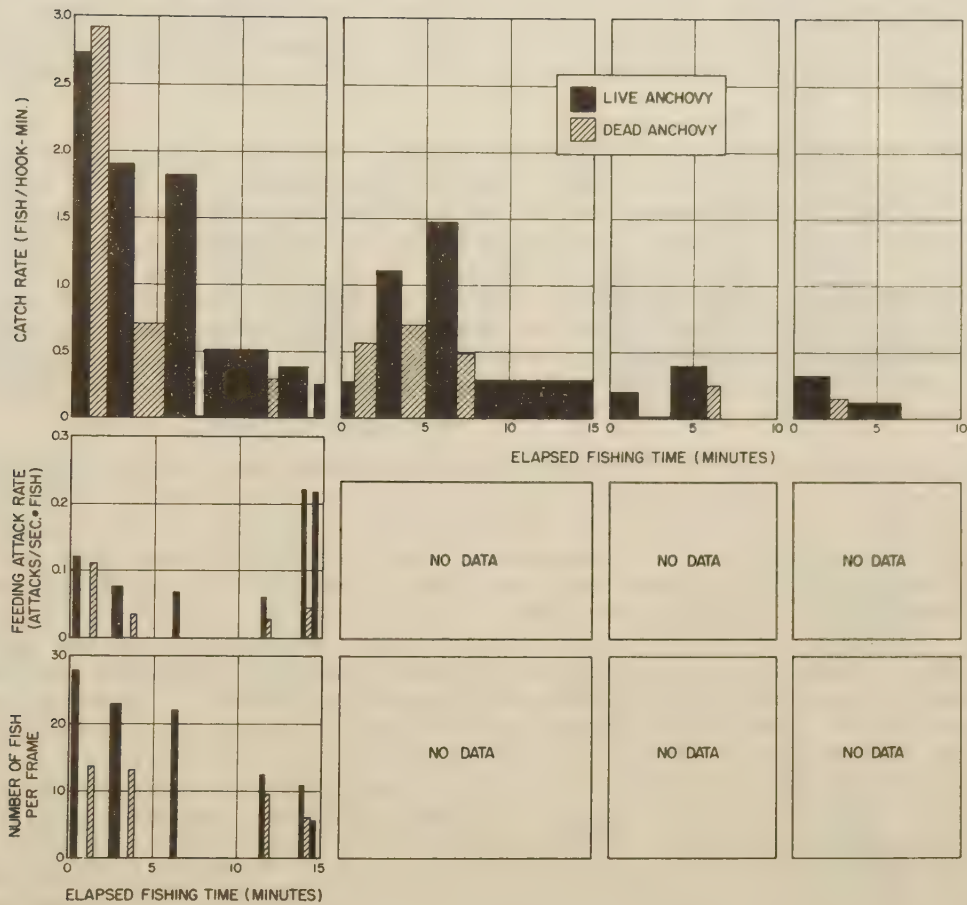


Fig. 1 Responses of skipjack tuna when live and dead anchovy were alternated as bait. Data on attack rates and numbers of fish apply only to the first experiment; conditions for photography were poor during the other three experiments.

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4 RESPONSES WITH AND WITHOUT WATER SPRAYS

Water sprays were alternately turned on and off during an experiment. Furthermore they were alternated in the initial periods with experiments; that is, if an experiment started with sprays on, the next started with sprays off.

The bait used in five of the ten experiments was live anchovy. Silversides (*Pranesus insularum*) and the young of mullet (*Mugil longimanus*), goatfish (*Mulloidichthys* sp.), mountain bass (*Kuhlia sandvicensis*) mixed with a few *Caranx* sp., and tilapia were used in one experiment each. The data were divided into two groups for analysis - those in which anchovies were used as bait and those in which species other than anchovy were used. Although it would have been desirable to treat each species individually, the number of tests with species other than anchovy was too small for separate statistical treatments.

The results are shown in Fig. 2 and 3. The use of water sprays improved the catch rates with both groups of bait ($p = 0.002$, $n = 31$ for anchovy; $p = 0.03$, $n = 17$ for other baits), but made no difference in the rate of feeding attacks ($p = 0.38$, $n = 10$ for anchovy; $p = 0.21$, $n = 14$ for other baits) and the concentration of fish at the ship ($p = 0.95$, $n = 10$ for anchovy; $p = 0.50$, $n = 15$ for other baits). The effect of water sprays on responses of skipjack tuna may be associated with the bait species. For instance, the catch rate appeared to be better without sprays when mullets were used as bait and unaffected by sprays when silversides were used as chum, and the feeding attack rate on goatfish seemed higher when water sprays were turned off. Since these were single trials, however, the results may not be dependable.

Although water sprays neither attracted more skipjack tuna to the ship nor stimulated greater rates of feeding attacks, they did improve catch rates. The data seem paradoxical, but a possible mechanism by which sprays contribute to the increase in catch rate may be suggested. If it is assumed that a skipjack tuna would not ordinarily take a hook because it is not a familiar food item, a hooked tuna represents an error in distinguishing between baitfish and hook. This error may arise under at least two circumstances: (i) the fish may be able to differentiate between bait and hook but strike at either because of competition or for other reasons; (ii) bait and hook may so closely resemble each other that differentiation is difficult. If many skipjack tuna were competing for food, more errors would be made because the fish would have to strike faster to obtain food. The rate of feeding attack would then rise. But in the present experiments the skipjack tuna were neither more concentrated nor feeding at a higher rate when the sprays were on. The sprays then must have raised the catch rates by increasing the difficulty of differentiating between bait and hooks - a possibility supported by a view of the books from underwater. When the sprays were on, the resulting surface disturbance caused a distorted appearance of the hooks and other objects (bait) in the zone within a few centimeters from the surface.

If this explanation is valid, the effectiveness of water sprays in raising the catch rate would depend on the physical and behavioural characteristics of the bait. Sprays would be most effective when bait and hook are distinguishable from each other without the sprays, but not with the sprays; sprays would not affect catch rate when bait and hook are so similar that the fish cannot ordinarily distinguish between them, or so different that bait and hook are readily distinguishable from each other even when the sprays are on.

Since the zone of visual distortion is very close to the surface, sprays should be effective only when bait is at the surface near the sprays and hooks. Since the bait is thrown into the area of the sprays, the effectiveness of the sprays in increasing catch rate, in practice, depends on how long the bait remains in the zone of visual distortion.

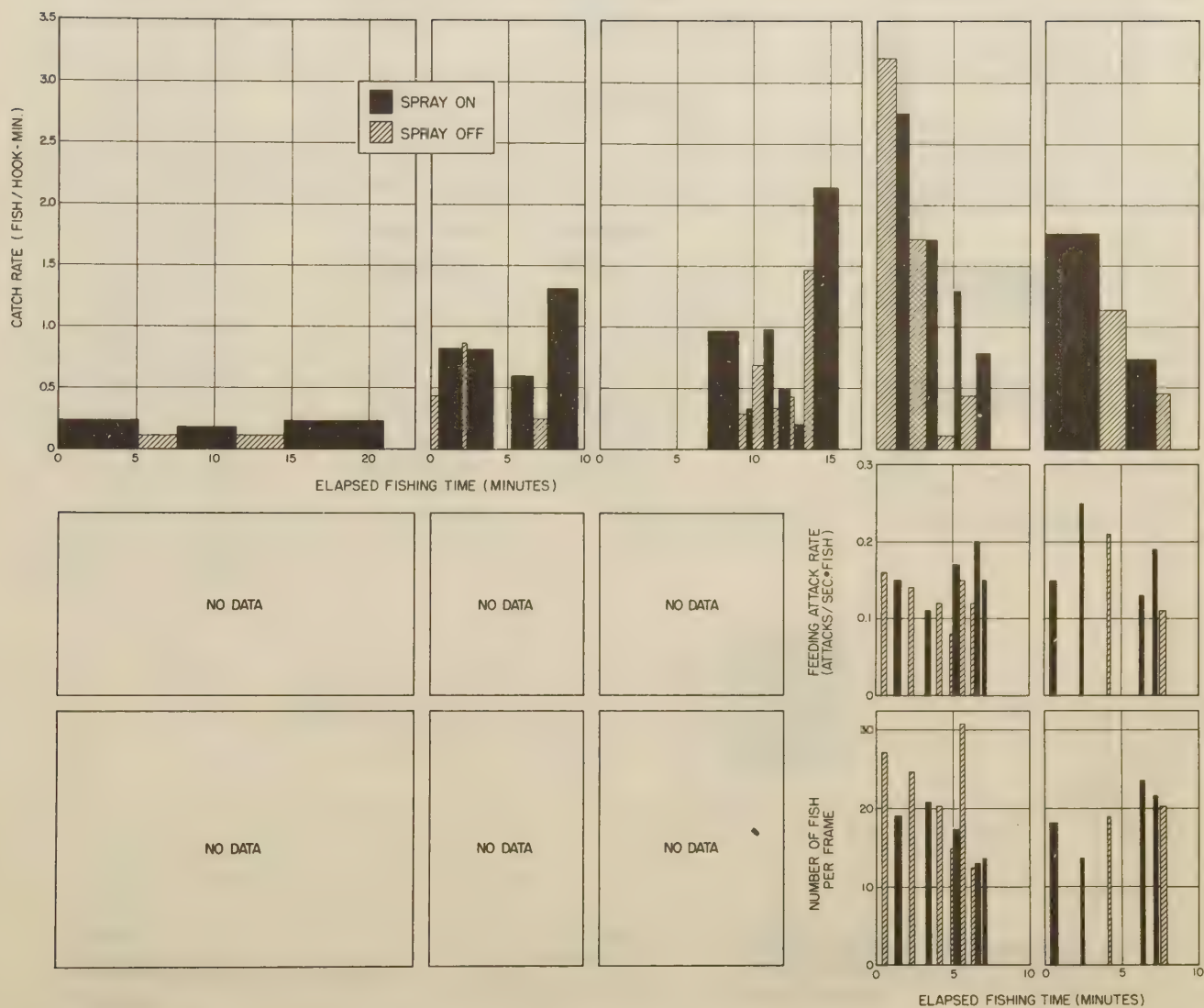
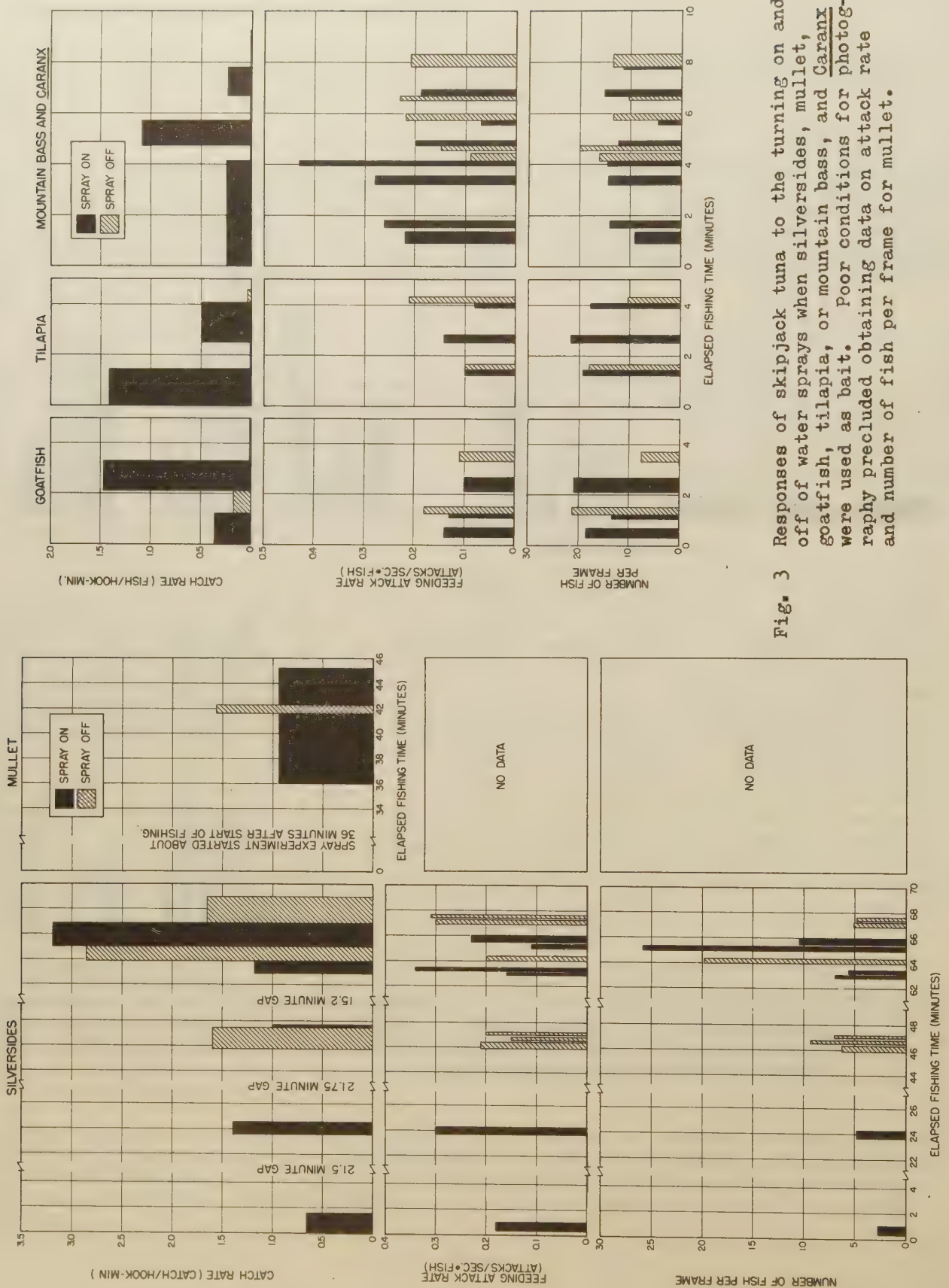


Fig. 2 Responses of skipjack tuna to the turning on and off of water sprays when anchovy was used as bait. Data on attack rates and numbers of fish per frame apply only to one experiment; conditions for photography were poor during the other three experiments.



5 RESPONSES TO LIVE TILAPIA AND ANCHOVY

The effectiveness of tilapia as bait was evaluated by comparing them with anchovy in tests on six schools of skipjack tuna. Fish 2 to 3 cm long were used, because larger tilapia dive immediately after release and are therefore not desirable as bait (Brock and Takata, 1955).

The species of bait used on the initial pass at a school was alternated from school to school. If more than one pass was required to lure the school to the ship, the species were alternated with each pass. The species which had successfully attracted the school to the ship was used during the first period of the experiment.

As mentioned earlier, the baits were changed at approximately 2-min intervals. Motion picture sequences were started at 40 sec and 80 sec after a bait change. No pictures were taken during the first 30 sec after a bait change because both species of bait were present during this period. The catch record for this transition period was recorded separately.

The responses of the skipjack tuna were similar in five of the six experiments. Fig. 4 shows a typical response pattern. Anchovy was decidedly superior to tilapia in terms of increased catch rate, feeding attack rate, and number of fish present (Table I). Even for school number 5 in Table I, for which the probabilities were higher than the conventional 5 percent acceptance level, the responses were higher with anchovy than with tilapia. Furthermore, anchovies lured all six schools of skipjack tuna to the ship, although the same number of passes were made with each species.

The conclusion that anchovy was more effective than tilapia as bait was also reached by Shomura (1964) in later experiments of a somewhat different design. He attributed the difference in catch to the greater resemblance of the shiny hooks to the silvery anchovy than to the dull tilapia.

TABLE I - Probabilities (p) that skipjack tuna responses to tilapia are equal to or better than their responses to anchovy. Probabilities are based on sign test. Number of comparisons per school is listed under n.

School number	Catch rate		Attack rate		Concentration of fish	
	p	n	p	n	p	n
1	0.001	14	<0.001	20	0.006	20
2	.011	10	.019	12	.003	12
3	.004	8	.011	10	.055	10
4	.004	8	.001	9	.004	8
5	.062	7	.387	12	.133	13
6	.002	9	.004	8	.004	8

Several notable differences in physical and behavioural traits between anchovy and tilapia could have caused the difference in responses. The anchovies swam in a way which caused the silvery lateral streak to flash in the light occasionally, whereas the tilapia were dark and swam inconspicuously. When tossed into the water tilapia formed a school 1 to 2 m below the surface and swam close to the ship. Anchovy, on the

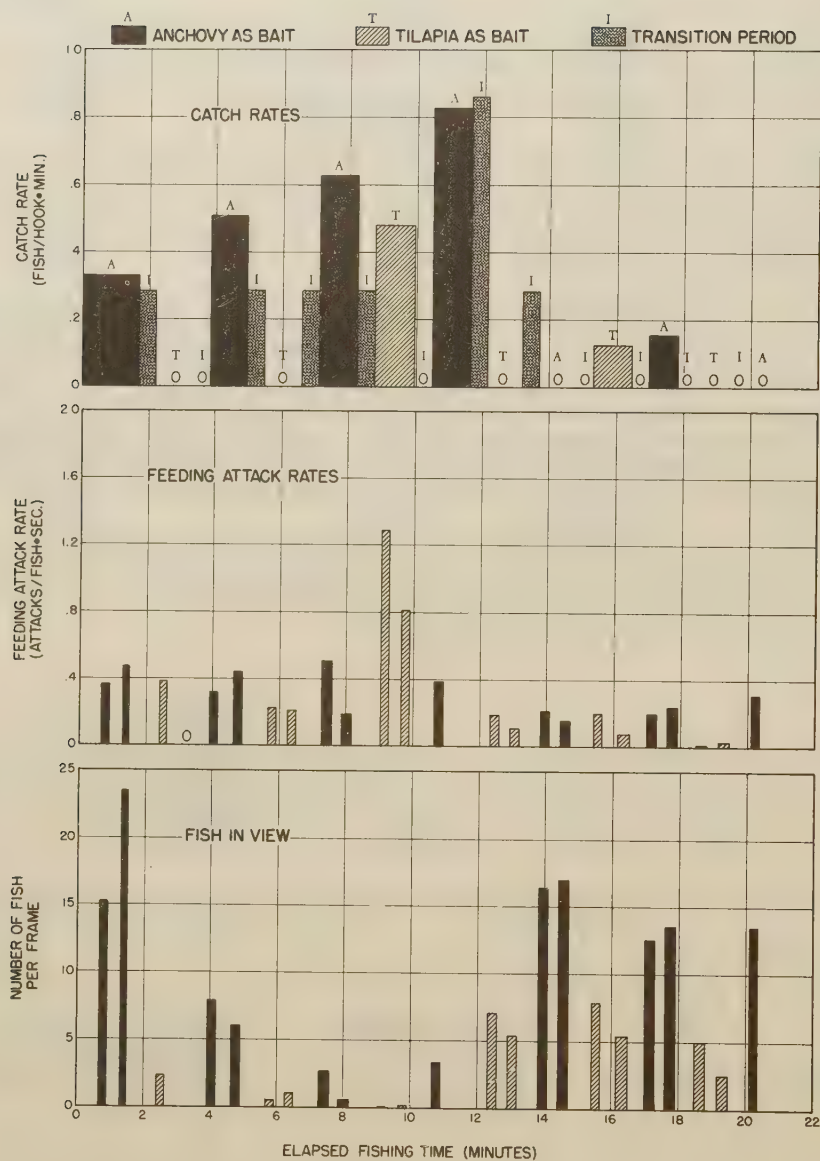


Fig. 4 Responses of one school of skipjack tuna when anchovy and tilapia were alternated as bait.

other hand, formed a school and dove down out of sight, but, more important, fled to the surface when they were pursued by skipjack tuna. Because anchovy are more conspicuous than tilapia, they should attract more skipjack tuna. Because feeding attacks are stimulated by the sighting of prey, the greater conspicuousness of the anchovy should evoke a greater number of feeding attacks. Because anchovy tend to flee towards the surface, a greater number of pursuing skipjack tuna should be available to the hooks.

Shomura (1964) pointed out that the ratio of the catch rate with anchovy as bait to the catch rate with tilapia as bait was 4:3 for skipjack tuna smaller than 55 cm and about 2:1 for those longer than 62 cm. The ratio for the skipjack tuna in the six schools of the present study (mean fork length, 32.3, 46.8, 55.4, 55.9, 61.3, and 63.3 cm) was 13:1. In his experiments, Shomura used only one species of bait for each school fished. He suggested (personal communication) that the experimental design of using anchovy and tilapia in alternating periods on the same school tended to exaggerate the difference between anchovy and tilapia. He argued that the skipjack tuna would become "conditioned" to anchovy and would, therefore, be looking for objects as conspicuous as anchovy during the periods in which tilapia was used as chum. Thus the tilapia would be likely to be overlooked.

6 SUMMARY

- (i) Responses of skipjack tuna were measured during pole-and-line fishing. Experimental fishing procedures were alternated with prevailing procedures (control). Three types of response were measured: (a) the catch rate, (b) the attack rate on bait, and (c) the number of tuna attracted to the fishing vessel.
- (ii) Live anchovies evoked a better response than dead anchovies in all three measures of response.
- (iii) The use of water sprays on the sea surface near the fishing hooks increased the catch rate, but made no difference in the attack rate nor in the number of fish present. These observations indicated that the effects of sprays depend on the bait species used.
- (iv) Anchovies evoked a better response than tilapia in all three measures of response.

7 REFERENCES

- Brock, V.E. and M. Takata, Contribution to the problems of bait fish capture and mortality together with experiments in the use of tilapia as live bait. 1955 Hawaii, Industrial Research Advisory Council, Grant No.49, Final report, 39 p.
- June, F.C., Preliminary fisheries survey of the Hawaiian-Line Islands area. Part 3. 1951 The live-bait skipjack fishery of the Hawaiian Islands. Comml Fish.Rev., 13(2):1-18
- Matsumoto, W.M., Experimental surface gill net fishing for skipjack (Katsuwonus pelamis) in Hawaiian waters. Spec.scient.Rep.U.S.Fish Wildl.Serv.(Fish.), 1952 90(90):20 p.
- Murphy G.I. and E.L. Niska, Experimental tuna purse seining in the central Pacific. 1953 Comml Fish.Rev., 15(4):1-12
- Shomura, R.S., Monofilament gill net fishing for skipjack tuna in Hawaiian waters 1963 (a progress report). FAO Fish.Rep., (6),vol.3:1177-99
- _____, Effectiveness of tilapia as live bait for skipjack tuna fishing. 1964 Trans.Am.Fish.Soc., 93(3):291-4

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Siegel, S., Nonparametric statistics for the behavioral sciences. New York,
1956 McGraw-Hill, 312 p.

Strasburg, D. W. and H. S. H. Yuen, Progress in observing tuna underwater at sea.
1960 J. Cons. int.Explor.Mer., 26(1):80-93

Tester, A. L., H. S. H. Yuen and M. Takata, Reaction of tuna to stimuli, 1953. Spec.
1954 scient.Rep.U.S. Fish Wildl.Serv.(Fish.) (134):33p.

Yuen, H. S. H., Variability of skipjack response to live bait. Fishery Bull.U.S.
1959 Fish Wildl.Serv., 60(162):147-60

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AVAILABILITY OF PACIFIC HAKE (Merluccius productus)
RELATED TO THE HARVESTING PROCESS

by

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Abstract

Information on the distribution, relative abundance and natural behaviour of Pacific hake (Merluccius productus) acquired during exploratory fishing surveys and from recently developed hake fisheries is summarized.

The hypothesis that the ocean hake stock spawns in offshore waters along southern California and Mexico during late winter and early spring and then migrates northward, primarily to continental shelf waters off the Pacific Northwest, is examined. Exploitation of the ocean stock is restricted to non-spawning fish and occurs mainly during the spring-fall period while they are feeding along the coast from Vancouver Island to Oregon. In contrast, the stock of hake in inland waters of Washington is most vulnerable to fishing during the winter-spring spawning period.

The distribution and behaviour of hake are such that they are most efficiently harvested using trawls capable of fishing both on and off bottom. Whether the ocean hake stock can be effectively exploited over the range in which it is found in commercial concentrations is unknown. Further studies of its distribution and behaviour, particularly with respect to spawning fish, are needed.

DISPONIBILITE DU MERLU DU PACIFIQUE (Merluccius productus)
EN FONCTION DU PROCEDE DE PECHE

Résumé

La communication récapitule les données sur la répartition, l'abondance relative et le comportement en milieu naturel du merlu du Pacifique (Merluccius productus), recueillies durant des campagnes de pêche exploratrice ou provenant de nouvelles pêcheries de ce poisson.

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L'auteur examine l'hypothèse selon laquelle les merlus de ce stock frayent au large de la Californie méridionale et du Mexique à la fin de l'hiver et au début du printemps, pour émigrer ensuite vers le nord, principalement sur le plateau continental du Pacifique Nord-Ouest. L'exploitation du stock océanique, limitée aux poissons non en période de reproduction, a lieu surtout du printemps à l'automne, époque où les poissons s'alimentent le long de la côte entre l'île Vancouver et l'Orégon. Par contre, le stock des eaux intérieures du Washington est extrêmement vulnérable à la pêche durant la fraie (hiver-printemps).

Etant donné la distribution et le comportement du merlu, la récolte la plus efficace sera obtenue au moyen de chaluts pouvant pêcher à la fois sur le fond et à une certaine distance de celui-ci. On ignore si le stock océanique peut être efficacement exploité dans tous les secteurs où il forme des rassemblements présentant un intérêt commercial. Il convient d'étudier plus avant sa répartition et son comportement, notamment pour ce qui est des poissons frayant.

DISPONIBILIDAD DE LA MERLUZA DEL PACIFICO (Merluccius productus)
EN RELACION CON EL PROCESO DE EXPLOTACION

Extracto

Se resume la información adquirida sobre la distribución, abundancia relativa y comportamiento natural de la merluza del Pacífico (Merluccius productus) durante los estudios de pesca exploratoria y en las pesquerías de merluza establecidas recientemente.

Se examina la hipótesis de que la merluza del océano desove en aguas fronterizas a la California meridional y México a finales de invierno y principios de primavera y de que posteriormente emigre hacia el norte, sobre todo a aguas de la plataforma continental del noroeste del Pacífico. La explotación de las poblaciones oceánicas se limita a los peces que no se hallan en desove, teniendo lugar principalmente durante el período de primavera-otoño, cuando se están alimentando a lo largo de la costa, desde la isla de Vancouver hasta Oregón. Por el contrario, las poblaciones de merluza de las aguas de Washington son más vulnerables a la pesca durante el período de desove de invierno-primavera.

La distribución y el comportamiento de la merluza son tales que se pueden capturar eficazmente por medio de redes de arrastre capaces de pescar en el fondo y por encima de él. Se ignora si se pueden explotar eficazmente las poblaciones de merluza en las zonas en que se encuentran en concentraciones comerciales. Se necesita efectuar nuevos estudios acerca de su distribución y comportamiento, especialmente con respecto a los peces en desove.

1 INTRODUCTION

The recent development of pelagic trawl fisheries for hake in the Pacific Northwest has emphasized the need for knowledge of factors influencing harvesting methods. This paper attempts: (1) to synthesize information on the spacial and temporal distribution and abundance of hake, and (2) to indicate how different availability patterns influence fishing techniques and strategy.

The Pacific hake is one of the several species of Merluccius harvested commercially. Its reported range is from the Gulf of Alaska (Alverson, Pruter and Ronholt, 1964) to the Gulf of California (Starks and Morris, 1907). It is a schooling, usually pelagic, fish which is common in coastal waters from Mexico to British Columbia. There is also a stock of hake in Puget Sound, Washington which apparently is distinct from coastal stocks. Hake are also found in inland waters of British Columbia.

Evidence from egg and larval surveys off southern California and northern Mexico as part of the California Cooperative Oceanic Fisheries Investigations (CalCOFI) has indicated that a very large spawning population of hake exists on the Pacific coast (Ahlstrom and Counts, 1955). Ahlstrom (1959) (and in other papers) pointed out that hake larvae rank second in abundance in annual estimates of larvae in the CalCOFI survey area. Despite the existence of this large resource, commercial exploitation of hake prior to 1965 was limited to a small fishery for animal food in California (Best, 1963) and to incidental catches taken mainly in fisheries for groundfish. Historically, Pacific hake were regarded (in the United States) as a nuisance species by commercial and sport fishermen.

Hake stocks in Washington-Oregon waters are now being significantly exploited by United States and Russian vessels. The U.S. catch is processed into fish meal for animal food. In contrast, the bulk of the Soviet catch is frozen in the round and sold for human consumption.

2 BACKGROUND

During the spring and summer of 1964, exploratory fishing surveys and fishing experiments with the COBB pelagic trawl (McNeely, Johnson and Gill, 1965) were conducted off the Washington-Oregon coast by the Bureau of Commercial Fisheries vessel JOHN N. COBB and the chartered vessel ST. MICHAEL. Large compact schools of hake were found on the continental shelf between Cape Flattery, Washington and southern Oregon. Catch rates in the COBB pelagic trawl were as high as 60,000 lb per 1/2-h haul. Catches of 15,000 lb per h trawled were consistently taken.

The work in 1964 demonstrated for the first time that hake congregated in dense schools over a large geographic area, and indicated that they might be available to pelagic trawls. Estimates of the potential magnitude and accessibility of the resource, and the expanding status of the world market for fish meal, spurred interest in further exploratory surveys, research on pelagic trawl gear and depth telemetry systems and study of the economic feasibility of harvesting and industrial processing. Consequently a fisheries development programme on hake was initiated and is still in progress. Various aspects of the program are discussed below.

A major portion of the hake research has involved exploratory surveys and gear development studies conducted aboard the JOHN N. COBB. Since 1964 the majority of its cruise time has been spent on pelagic surveys for hake in coastal waters between British Columbia and Mexico and in Puget Sound.

During the summer of 1965 the Bureau of Commercial Fisheries chartered the WESTERN FLYER for simulated commercial hake fishing with the COBB pelagic trawl. Fishing trials took place off the Washington-Oregon coast. Hake were delivered to a reduction plant

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in Oregon. Although the availability of hake was less than in 1964 (possibly because of a high temperature anomaly which existed off the west coast of the United States in 1965) valuable data were obtained on methods of detecting, harvesting, and handling hake. Also in 1965, the ST. MICHAEL was used for testing modifications of the COBB pelagic trawl off the Washington coast and in Puget Sound.

In November 1965 the ST. MICHAEL conducted experimental fishing in Saratoga Passage, Puget Sound, on large concentrations of hake previously discovered by the JOHN N. COBB. Shortly thereafter, in a cooperative arrangement between the Bureau and vessel owners a hake fishery was initiated in Puget Sound. This fishery, which has now completed two seasons (fall to spring, 1965-66 and 1966-67), has been profitable for the participants, and has yielded a great deal of information on the harvesting and handling processes, particularly with respect to the capabilities of pelagic trawl gear and electrical depth telemetry. Vessel owners were loaned either COBB pelagic trawls and a depth telemetry system or a depth telemetry system only. They reciprocated by keeping detailed records on catches and fishing effort and allowing Bureau personnel on board for observations of their fishing operations and for biological sampling. The development of the fishery and results during the 1965-66 season have been discussed by Hipkins (1966).

In the spring of 1966 a fish meal plant was built in the city of Aberdeen near the Washington coast in anticipation of the exploitation of coastal hake stocks. The coastal fishery was initiated in July with four vessels participating. Vessel owners were loaned depth telemetry system and built their own midwater trawls based on Bureau designs. The U.S. vessels were in direct competition with a massive Soviet fleet (111 vessels) which had begun to exploit hake and groundfish off the Washington-Oregon coast in mid-May.

The U.S. fishery harvested only 3.7 million lb of hake whereas, between May and November, the Soviet catch was approximately 300 million lb. The relatively small size of the U.S. catch was attributed to the large Soviet catch, the small size and limited scouting ability of the U.S. fleet, and limited operating space within the Soviet fleet in areas where hake were abundant. Also, in contrast to previous years, hake were often concentrated on bottom and were less available to midwater gear.

A net, similar to the COBB pelagic trawl but modified to fish on or off bottom, was designed and constructed by the Bureau of Commercial Fisheries during the winter of 1966-67. This design is now being used in the 10-vessel U.S. fishery which began operating off the Washington coast in Mid-May, 1967.

3 MATERIALS AND METHODS

3.1 Sources of data and analysis procedure

This paper brings together: (1) observations on abundance, distribution, and behavior obtained mainly during exploratory surveys and gear research studies, and (2) an analysis of catch and effort data from the recently developed fisheries. Since fishery data are limited, and because surveys were of an exploratory nature, rigorous treatment of the data was not warranted. Rather, what may be described as preliminary observations on trends in hake availability are described in an attempt to ascertain the probable import of such trends on harvesting tactics. It is hoped that, as a byproduct of this procedure, the more important characteristics of the apparent pattern of availability will be put more clearly in focus. Because sufficient data are not available, little attempt is made to discuss possible effects of environmental factors regulating hake distribution and abundance.

Cruise reports and unpublished observations on exploratory surveys and gear research studies have provided a variety of information not specifically cited. Sources of hake catch and effort data include: (1) the simulated production trials of the WESTERN FLYER in 1965, (2) the 1965 to 66 and 1966 to 67 Puget Sound fisheries, and (3) the 1966 U.S. fishery off the Washington coast. Population data on hake have been collected by both

the Groundfish Investigations Section of the Bureau of Commercial Fisheries Biological Laboratory and the Exploratory Fishing and Gear Research Base.

Information collected by commercial vessels included for each trawling station: location, date, time of day, duration, bottom depth, net depth, information on gear performance and weight estimates for each of the more important species caught.

3.2 Vessels and gear

With the exception of two halibut schooners currently operating in the coastal hake fishery, vessels which have engaged in hake exploratory surveys and in gear research studies, as well as those which have participated in the fisheries, are all West Coast multipurpose seiner-type trawlers equipped with powered drums for trawl retrieval. Hanson (1955) describes a multipurpose seiner. Wathne (1959) and Alverson (1962) discuss drum trawling. The vessels range in length from 56 to 93 ft. Horsepower of the vessels varies from 200 to 510.

Although research vessels have tested various pelagic gear and acoustical telemetry systems, commercial vessels have usually been equipped with both COBB pelagic trawls and electrical depth telemetry.

The basic design of the telemetry system used with the COBB pelagic trawl has been described by Lusz (1965). Since Lusz's publication, the durability and efficiency of the system have been continually improved. The system presently employed is accurate to within two percent at the most commonly encountered trawling depths. Extensive testing has shown that midwater trawling for hake with precise depth telemetry is essentially futile.

4 RESULTS

4.1 Annual migration and seasonal abundance of coastal hake stocks

With respect to the distribution and relative abundance of Pacific hake on an annual basis, two phenomena are readily discernible: (1) the presence of large quantities of hake eggs and larvae in offshore waters along the coast of southern California and northern Mexico during the months of February, March, and April; and (2) the occurrence of dense schools of adult hake off the coast from northern Oregon to southern Vancouver Island, British Columbia during the period May to October. Smaller concentrations are found between central Oregon and southern California. In the absence of data to the contrary, the hypothesis has been advanced that these two events are directly correlated; i.e., there exists a southward movement of the bulk of the adult hake population in late fall and winter to spawning grounds off southern California and Mexico, and a return movement, mainly to continental shelf waters off Oregon and Washington, in the spring (Fig. 1). Factors controlling the migration of hake are unknown.

Although direct evidence is lacking, support for the concept of an annual north-south migration includes: (1) the absence of hake eggs and larvae except in California-Mexico waters, (2) a paucity of hake in the Oregon to Vancouver Island coastal waters during the period November through April, (3) the occurrence of young fish only in southern Oregon and California waters, and (4) the relatively low abundance of hake between southern California and central Oregon and north of central Vancouver Island, British Columbia. A Soviet survey (Anon., 1966, unpublished MS) also showed that "hake migrate seasonally during the spring and summer in a northerly direction and during the fall in a southerly direction," in the Northern California to Vancouver Island area (38° to 50° N lat).

4.1.1 Occurrence of hake eggs and larvae north of Southern California An extensive egg and larval survey was conducted between the California-Oregon border and the northern end of Vancouver Island during April and May, 1967. Plankton hauls were made to a depth of 220 m on tracklines located along each whole degree of latitude between

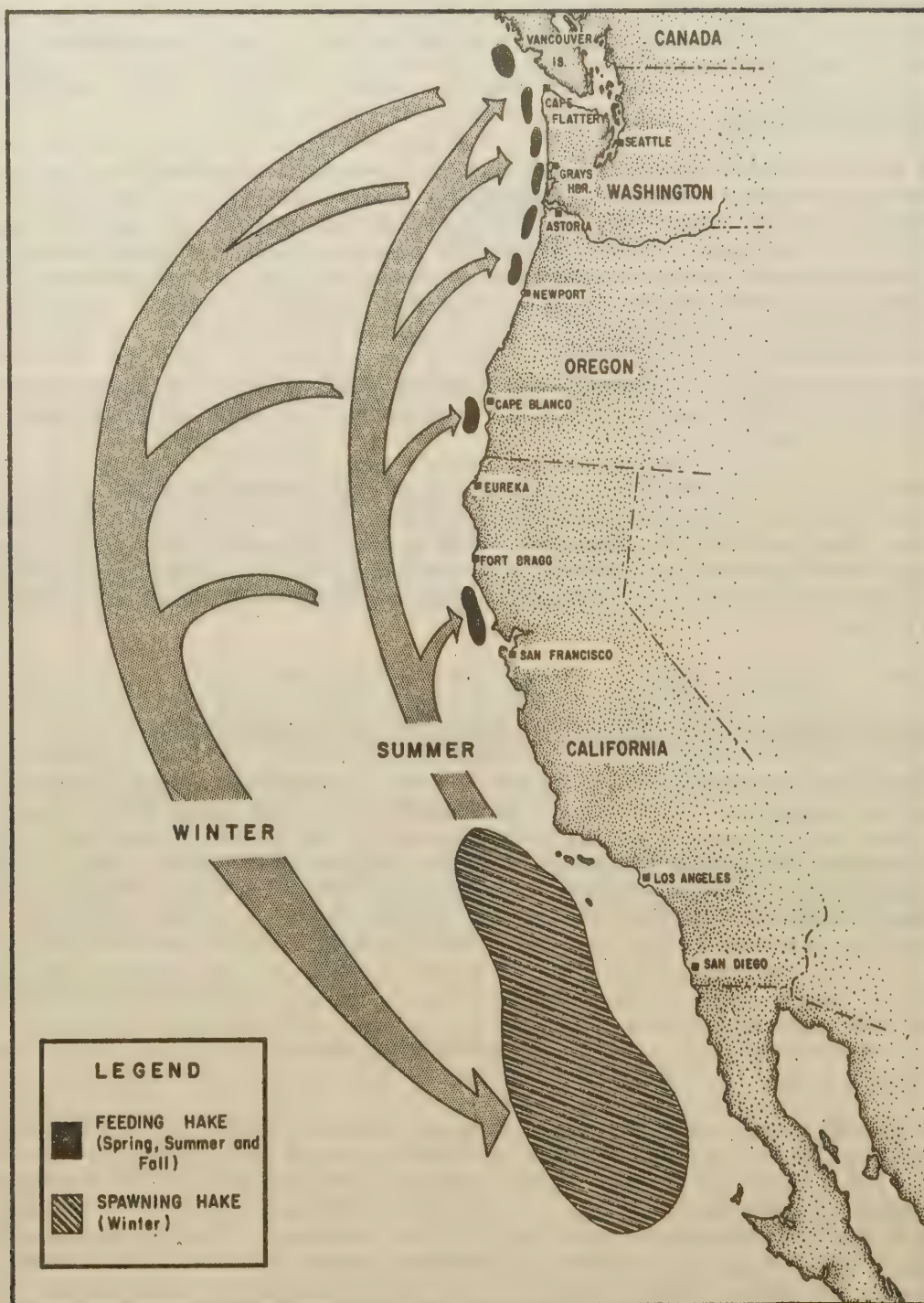


Fig. 1 Hypothesized migration and distribution of Pacific hake (*Merluccius productus*)

42° and 51°N lat. Station tracks were from the 30 fm isobath to 300 mi off-shore. No hake eggs or larvae were encountered (Kenneth Waldron, personal communication). Also, no eggs or larvae were taken during sampling along the Washington-central California coast in February 1965. To date there is no record of hake eggs and larvae being found north of California.

4.1.2 Relative abundance of hake off Oregon-Vancouver Island coast from November to April Although minor quantities of hake can be found along the coast from Oregon to Vancouver Island throughout the year, the abundance of hake present during the period November to April is negligible. This is evident from the incidental catches of the ground fisheries, as well as from the results of exploratory surveys. It appears highly improbable that recruitment from local stocks contributes significantly to the large population available from May to October in this area.

4.1.3 Occurrence of young hake Hake caught off the Oregon to Vancouver Island coast generally range from 40 to 70 cm in fork length. Fish in this size range are 4 to 10 yr old adults. During the period May to October they change from a post-spawning to a prespawning condition. Hake shorter than 40 cm are rarely observed. Despite several hundred research vessel drags with both pelagic and demersal trawls equipped with small (usually $\frac{1}{2}$ in) mesh codend liners, hake shorter than 30 cm have not been recorded north of southern Oregon. Of 3,860 fish sampled from U.S. commercial vessels in 1966 none were shorter than 40 cm (Kenneth Waldron, personal communication). This is not due to gear selectivity since the 2 to 3 in mesh (stretched measure) used in hake trawls is capable of capturing much smaller fish. This is evident from theoretical considerations and from the size composition of hake caught in Puget Sound.

Similar data on size composition were obtained during Soviet research investigations in the northern California to Vancouver Island area in 1965 (Anon. *ibid*). Of 631 fish measured during the period May to October only 5 were less than 40 cm. These included specimens 38 cm (4) and 36 cm (1) in length.

Best (1963) found that 2.8 percent of 4,644 hake sampled from commercial landings in California were shorter than 40 cm (total length). However, in contrast to the Washington-Oregon data, fish as small as 12 cm were reported by Best. His samples were taken in $4\frac{1}{2}$ in mesh otter trawls. Morgan and Gates (1961) found hake as small as 14 cm off southern Oregon and northern California. Samples were obtained from shrimp trawls with $1\frac{1}{2}$ and $1\frac{5}{8}$ in mesh codends. Shrimp trawlers off southern Oregon have occasionally taken hake as small as 12 cm (various personal communications). Soviet studies of hake size composition (Anon. *ibid*) showed the relative quantity of young fish increased to the south in the area between 38° and 50°N lat.

The available data indicate young hake (to about age 3) are restricted to southern Oregon-California waters. Hickling (1933) reported that European hake (*M. merluccius*) are not taken on bottom in significant numbers until the end of their second year when they average about 20 cm in length. If this is true for Pacific hake, then a low abundance of juvenile fish should be expected in the southern Oregon-California demersal fisheries regardless of the trawl mesh size employed.

4.1.4 Abundance of hake between southern California and central Oregon and north of central Vancouver Island U.S. pelagic survey data for the area between southern California and central Oregon indicate that during the spring to fall period hake are less abundant in that area than in the area between central Oregon and Vancouver Island. Soviet surveys (Anon. *ibid*) in 1965 revealed essentially the same picture of relative abundance. Soviet results are subject to the qualifications that they were carried out using a herring bottom trawl and the area inside the 50 m

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isobath was not surveyed. Therefore, schools close to the coast, and pelagic schools were not fished. During the "spring" (dates not given) of 1965, hake were concentrated in the northern Oregon-southern Washington area (approximately 44°20' to 47°00' N lat.). During the period August to October hake concentrations were larger in size and generally denser. In addition to the area in which hake were found in the spring, which by the August to October survey extended one degree of latitude farther south, the area between northern Washington and Vancouver Island (approximately 48°00' to 49°30' N lat.) also contained a large population of hake. A smaller, isolated concentration was found at the California-Oregon border (46° N lat.). No significant concentrations of hake were found between 38° and 43° N lat. during either of the Soviet surveys.

The California animal food fishery for hake, conducted mainly from northern California ports, has produced approximately one million lb annually. In northern California ports (Eureka, Fort Bragg and San Francisco) 85 to 92 percent of the catch is landed between April and September, whereas in more southern ports (Monterey and Morro Bay) 72 to 78 percent of the catch is produced during these months (Best 1963). Unfortunately, since the California fishery is a limited one utilizing bottom trawls, it is at best a crude index of hake abundance relative to that in other areas.

Hake have not been observed in any abundance north of central Vancouver Island (49°30' N lat.) during either U.S. or Soviet surveys. In their study of the demersal fish communities of the northeastern Pacific, Alverson, Pruter and Ronholt (1964) found hake to be of minor importance north of the Vancouver Island area. The boundary between the Transitional and Central Subarctic Domains of the north Pacific, described by Dodimead, Favorite and Hirano (1963), occurs off northern Vancouver Island. Alverson, Pruter and Ronholt (1964) noted that south of this boundary (in the warmer and more saline Transitional and California Undercurrent Domains) hake appeared to replace cod (Gadus macrocephalus) and pollock (Theragra chalcogrammus) in the roundfish community.

4.1.5 Adult hake in southern California-northern Mexico waters Each year from 1963 through 1966 pelagic surveys were conducted in southern California-northern Mexico waters during the hake spawning period. These surveys, carried out in co-operation with the Bureau of Commercial Fisheries Laboratory, La Jolla, California, were designed to give coverage to those areas in which hake eggs and larvae occurred in maximum abundance. Since hake spawn over a large offshore area, considerable difficulty was experienced in locating fish. Severe weather often reduced the time for, and the efficiency of searching operations.

Although large catches of hake were rarely made in the spawning region, substantial bodies of spawning and near spawning fish were encountered. In one instance fish were found to be continuously present in an area covering 1,600 mi². Generally the hake were located at depths of 200 to 250 fm over bottom depths of several hundred fm. Fish found at these depths were loosely aggregated over broad areas in bands 25 fm thick. Although the horizontal and vertical dimensions of the hake concentrations were often large, their density was uniformly low.

On one occasion a dense, actively spawning hake school (composed almost entirely of running-ripe fish) was located at a depth of 100 to 125 fm. Catches up to 20,000 lb per h were taken in this school. The school was observed continuously during a period of 6 days. Throughout this time it maintained its shape and position and moved at a constant rate of 5 mi per day in the same general direction.

4.2 Bathymetric distribution and movements of coastal hake stocks

Certain features of the bathymetric distribution and movements of hake in the Oregon-Vancouver Island area during the months of May through October have been elucidated by pelagic surveys and data from the recently developed hake fishery. These are referred to below, following general comments on the bathymetric distribution of hake.

Surveys indicate that, except while spawning, hake are primarily residents of the continental shelf. They are found beyond the continental slope less frequently; although this observation may be a result of the limited survey and fishing efforts in deep water. Usually they remain within 10 fm of the bottom. Schools located high off the bottom during the day are characteristically in close proximity to the edge of the continental shelf of submarine canyons to which they apparently orient.

Data from the otter trawl fishery in northern California indicate roughly 90 percent of the catch is taken on the continental shelf (Best 1963). Soviet bottom trawl surveys between northern California and Vancouver Island (Anon. *ibid*) did not locate commercial concentrations of hake beyond a depth of 400 m. The highest catch per unit of effort for hake recorded by Alverson, Pruter and Ronholt (1964) occurred on the outer continental shelf in the Washington-Oregon region.

A few workers have reported on the extremes of the bathymetric range of Pacific hake. Clemens and Wilby (1961) reported hake captured as deep as 491 fm off California. Alverson (1951 and 1953) noted that a few hake were encountered at 300 to 304 fm off Washington. Alverson, Pruter and Ronholt (1964) found that hake were not present deeper than 299 fm in areas north of the Washington-Oregon region, the southern-most locale included in their study. On occasion hake range close inshore. DeWitt (1952) observed hake stranded in the surf while chasing prey. Van Hyning and Ayers (in Best 1963) observed them in the Columbia River estuary in brackish water.

4.2.1 Relative abundance and movements of hake in the Oregon to Vancouver Island area The dynamics of the movement of hake onto continental shelf waters off the Oregon to Vancouver Island coast during the spring and summer are not well understood. The hake population apparently does not migrate north in waters overlying the continental shelf as it begins to occupy that area along the Oregon and southern Washington coast between April and June. Rather, it appears to move mainly in deeper water, probably along the edge of the shelf, and then to colonize different banks, particularly on the inner shelf. It appears that during the late May through June period in each of the years 1965 to 1967 the bulk of the hake population present along the Washington-Oregon coast has resided in inner shelf waters (<50 fm) between Tillamook Head, Oregon, and Grays Harbor, Washington (Fig. 2). Smaller bodies of hake have been found southward to Heceta Bank off Newport, Oregon and northward to Destruction Island, Washington. From mid-summer until the southward migration in late fall the relative abundance and distribution of the population is less well known. During this period there is additional recruitment onto the shelf (as noted previously in connection with the results of Soviet surveys) and at the same time changes in relative abundance with respect to geographic area take place. Areas along northern Washington and southern Vancouver Island become more densely populated than earlier in the season. At the same time the abundance of hake present off southern Washington and northern Oregon tends to decrease.

Catch and effort statistics from the 1966 coastal hake fishery off the Oregon to Vancouver Island coast provide some indication of the nature of bathymetric and geographic movements during the summer. The fishery, in which four vessels participated, began on July 5 and ended on October 7. Because of the limited amount of data available it has been necessary to resort to separate treatment of individual variables affecting catch and effort.

Table 1 shows fishing effort and catch per unit of effort in five areas (Fig. 2) by season. The majority of the fishing effort occurred between Grays Harbor and the Columbia River (area 2) during both the July to August and September to October periods. Also in May and June the majority of the Russian fleet operated in this area. The data are insufficient to calculate reliable variance estimates for the catch per unit of effort figures. However, some of the area and period differences are worth noting. It should be mentioned that the concentration of fishing effort in area 2 during both time periods was partially due to that area's relatively short distance from port. In the July to August period the catch per unit of effort was highest in

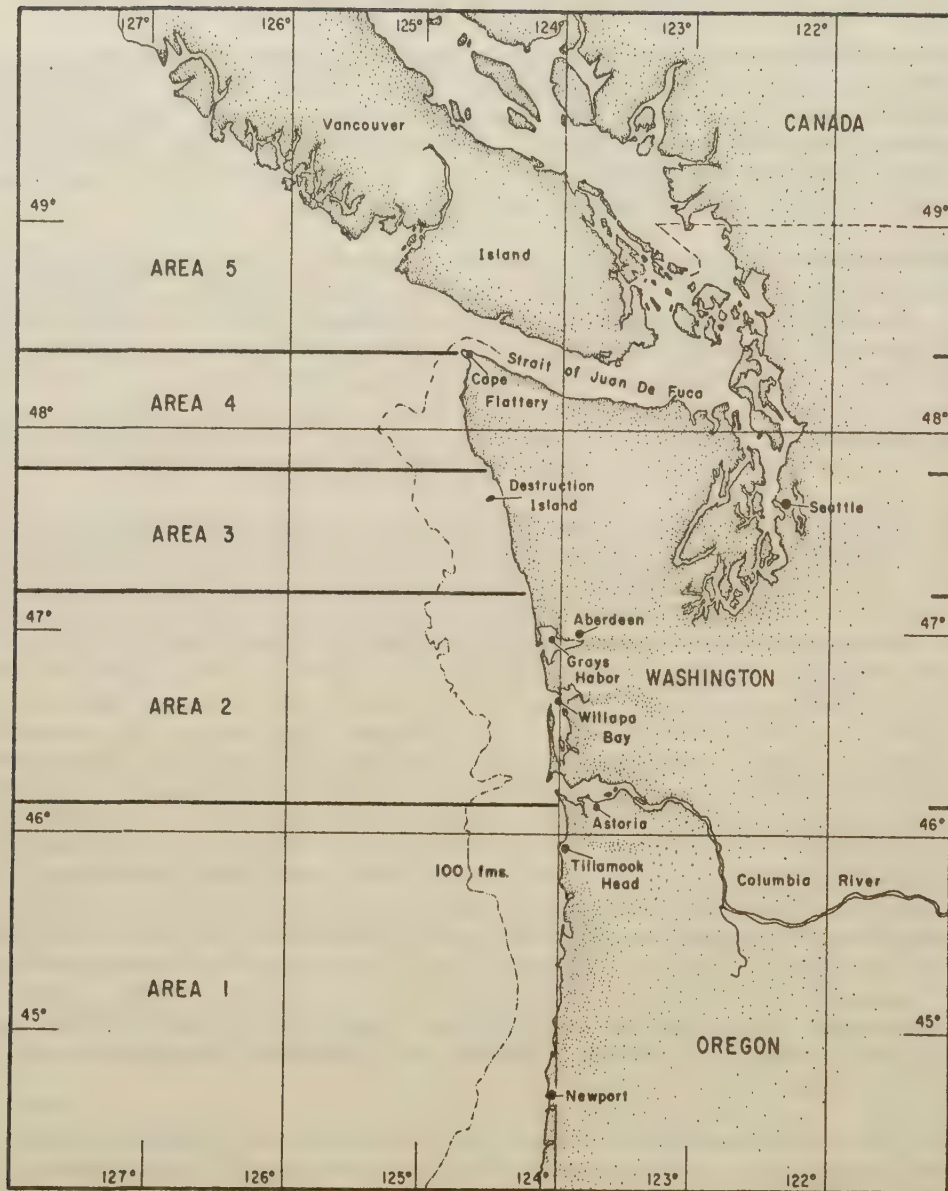


Fig. 2 Washington-northern Oregon coastal region fished by U.S. hake vessels in 1966. Almost all fishing occurred inside 100-fm isobath.

TABLE I - Fishing effort in hours (f) and pounds of hake caught per hour (c/f), by area and period, during 1966 U.S. hake fishery off Oregon-Vancouver Island coast. See Fig. 2 for area boundaries.

PERIOD	AREA									
	1		2		3		4		5	
	f	c/f	f	c/f	f	c/f	f	c/f	f	c/f
July - Aug.	1.6	2,800	296.3	6,600	38.8	4,000	23.9	5,900	47.3	5,300
Sept. - Oct.	-	-	75.1	2,600	47.3	19,000	17.6	8,700	3.3	700

area 2. This appears to be a reasonable estimate of the rank of this area with respect to the abundance of hake during that period. Survey results indicate it was not a function of variability due to the relatively minor fishing effort in other areas. The distribution of effort and catch per unit of effort in the September to October period was quite different from that witnessed earlier. Between the two time periods the percentage of fishing effort expended in areas north of area 2 shifted from 27 to 49. Concurrent with this shift in effort there was a marked change in catch per unit of effort with respect to area. Even though the amount of fishing effort was comparatively minor in all areas during the last part of the season, the magnitude of the differences between area 2 and areas 3 and 4 indicates a significant change in the abundance of hake occurred. The increase in abundance in more northern areas during the latter part of the season is in accord with survey results referred to above.

As mentioned earlier hake congregate primarily on the inner continental shelf as they populate the coastal region during the spring and early summer. Significant concentrations outside this area, if present, are generally found adjacent to the edge of the continental shelf. As the summer progresses there is a definite tendency for hake to become more abundant in deeper water. Even though data are not available for May and June this trend is apparent in the hake fishery statistics. In late summer there was a significant increase in catch per unit of effort between the 40 and 80 fm isobaths. A corresponding decrease, of lesser magnitude, was observed inside 40 fm. Data from outside 80 fm are too limited to consider. The dynamics of this shift in abundance are a matter of conjecture. Limitations of the data prevent attempting to segregate the effect of an offshore movement from that of new recruitment.

It appears that bathymetric and geographic movements of hake in the Oregon to Vancouver Island area are partially influenced by the availability of euphausiids, their primary food, during the spring-fall period (Alton and Nelson, MS). Studies are now being undertaken to determine the importance of euphausiids and other prey in controlling the availability of hake during the spring-fall period.

Although Russian vessels were observed making small catches of hake off Destruction Island in early November 1966, virtually nothing is known of the distribution and movements of the hake population between November and February. Consistently adverse weather during late fall and winter months has hindered determining the pattern and rate of movement away from the Oregon to Vancouver Island area.

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TABLE II - Fishing effort in hours (f) and pounds of hake caught per hour (c/f) trawled, by bottom depth and period, during 1966 U.S. hake fishery off Oregon-Vancouver Island coast.

Bottom depth (fathoms)	Period			
	July 5 - August 15		August 16 - October 7	
	f	c/f	f	c/f
< 40	118.2	7,300	140.7	4,400
41 - 80	147.4	4,600	106.3	12,000
81 >	33.8	4,600	4.8	1,300

4.3 Abundance of hake in inside waters

Pacific hake have been found throughout Puget Sound and adjacent inside waters of Washington; i.e. the Strait of Juan de Fuca, the Strait of Georgia, and the San Juan Islands (Fig 3.). However, the relative abundance of hake in inside waters differs significantly among areas. In most localities hake have not been observed in large quantities. Commercial quantities of hake have been found only in the Saratoga Passage-Port Susan area (Fig. 3). Large numbers of eggs and larvae have been found only in Port Susan. Much smaller quantities have been found in southern Puget Sound, Hood Canal, and in the vicinity of Possession Sound. It is in the Saratoga Passage-Port Susan area that the fall-spring fishery, mentioned previously, has taken place in recent years.

For all practical purposes the hake stock in inside waters can be considered distinct from that off the coast. The two stocks are similar in that both mature between ages three and five and have nearly the same age span. However, for any given age, hake from inside waters are substantially smaller; e.g. there is a 15 to 20 cm difference in mean length between the two stocks at ages four and five.

4.3.1 Seasonal abundance of hake in the Saratoga Passage-Port Susan area

Catch and effort data from the fishery in the Saratoga Passage-Port Susan area provide a means of following the relative abundance of hake in that area during the fall-spring period. Survey data relating to temporal changes in abundance in other areas are insufficient to attempt interpretation.

Table III shows the catch per unit of effort and the amount of fishing effort in Saratoga Passage and Port Susan for each month the fishery operated during the 1965 to 66 and 1966 to 67 seasons. Pertinent features of the data are:

- (1) the absence of fishing in the Saratoga Passage area after January
- (2) the high catch rates observed in Port Susan during February, March and April, and
- (3) the decline in catch rates after April



Fig. 3 Puget Sound and adjacent inland waters of Washington

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TABLE III - Fishing effort in hours (f) and pounds of hake caught per hour (c/f), and number of vessels operating by month, in Saratoga, Passage and Port Susan, Puget Sound during 1965 to 66 and 1966 to 67 hake fishing seasons. 2/

1965-66					
Month	No. of vessels	Saratoga Passage		Port Susan	
		f	c/f	f	c/f
Nov.	1	22.9	14,000		
Dec.	1	38.9	10,500		
Jan.	1	8.9	4,900		
Feb.	2			70.3	21,000
March	2	1.0	200	50.1	24,200
April	2			10.7	32,700
May	1			51.7	10,100
June	1			11.4	3,200

1966-67					
Month	No. of vessels	Saratoga Passage		Port Susan	
		f	c/f	f	c/f
Sept.	1	19.7	9,200		
Oct.	1	94.2	9,000		
Nov.	1	70.4	7,800		
Dec.	4	48.8	4,200	10.8	7,600
Jan.	4	28.2	7,800	206.3	6,600
Feb.	4			276.0	10,000
March	4			153.8	11,200
April	3			103.5	7,100
May	2			65.5	4,500

This sequence of events apparently corresponds, respectively, with the following phenomena:

- (1) a drop in the abundance of adult hake (which are mainly in a prespawning condition) in the Saratoga Passage area due to migration to Port Susan

2/ Data include only those from vessels loaned Bureau of Commercial Fisheries gear.

- (2) the presence of extremely dense schools of hake in Port Susan which grade in maturity from a prespawning to a spent condition, and
- (3) the migration of spent fish out of the Port Susan area

Before commenting further, it is necessary to qualify the data presented in Table III. During the 1965 to 66 season fishing did not take place in Port Susan during January because hake were not discovered there until February. Differences between seasons in the amounts of fishing effort expended each month, besides being related to the number of vessels operating, were partially created by highly unstable market conditions. For example, no fishing took place between April 6 and May 7 during the 1965 to 66 season because a market was not available. Although the catch per unit of effort data are somewhat affected by variation in fishing power among vessels, it can be shown this does not significantly alter the indicated trend in abundance. The contrast between the average catch rate in Saratoga Passage and the catch rate in Port Susan during the February to April period was substantially more evident in 1965 to 66 than in 1966 to 67. Also, the catch rate for the season as a whole was substantially higher in 1965 to 66. The reasons for these phenomena cannot be considered here.

Discussion of the relationships between changes in size, sex and maturity composition and the observed trend in abundance are outside the purview of this paper. However, various biological data are available which support the inferences regarding movements and maturity mentioned above. This is true for both the 1965 to 66 season (Larkins *et al.*, unpublished MS) and the 1966 to 67 season (Kenneth Waldron, personal communication).

Direct evidence of an emigration of hake from Saratoga Passage to Port Susan is lacking. However, the simultaneous occurrence of a decrease in abundance in Saratoga Passage and an increase in Port Susan, and the magnitude of these changes, are considered good evidence of a movement between the two areas. Survey observations suggest recruitment to the spawning stock in Port Susan from areas other than Saratoga Passage is relatively minimal. The area in which the Port Susan spawning stock resides during the summer (roughly June to September) is unknown.

4.3.2 Bathmetric distribution of hake in Saratoga Passage-Port Susan area
Saratoga Passage and Port Susan are steep-sided basins. Bottom depth in Port Susan is almost uniformly 55 to 66 fm; the maximum depth is 66 fm. Hake fishing in Saratoga Passage takes place primarily in the northern half of the area. The average bottom depth in this section is approximately 40 fm. Bottom depth in the southern half of the area averages between 50 and 70 fm; maximum depth is 99 fm. Catch and effort data segregated according to bottom depth indicate hake are found distributed throughout each of the areas; i.e., maximum fishing effort and catch rates occur over average bottom depths (Table IV).

4.4 Vertical distribution, schooling, and diel behaviour of hake

The diel movement pattern of hake, fluctuations in the depth at which they are found off the bottom, and the relative compactness and size of schools are complex, interrelated phenomena which significantly affect the conduct and success of fishing. Diel vertical migrations involving a movement away from the seabed at nightfall and a descent back towards the bottom near dawn have been reported for various species of hake (*M. merluccius*, Hickling 1927; *M. gayi*, Poulsen 1952; *M. hubbsi*, Angelescu, Gneri and Nani 1958, and Angelescu and Fuster de Plaza 1965; and *M. productus*, Alton and Nelson, *ibid*). Vertical migrations, common to many marine fishes, have usually been associated with changes in feeding and/or light conditions. However, as Brunel (1965) has indicated, because of the difficulties involved in attempting to isolate causal factors and of verifying the depth at which prey are consumed, data have rarely, if ever, been sufficient to demonstrate a definite cause and effect relationship.

TABLE IV - Fishing effort in hours (f) and pounds of hake caught per hour (c/f) by bottom depth in Saratoga Passage and Port Susan. Data for 1966 to 67 seasons combined. 3/

Bottom Depth (fathoms)	Saratoga Passage			Port Susan		
	No. of hauls	f	c/f	No. of hauls	f	c/f
21-30	12	12.3	6,800	-	-	-
31-40	125	184.0	8,800	1	1.0	3,000
41-50	68	81.1	8,900	11	12.1	8,800
51-60	8	10.1	6,800	92	105.4	11,300
61-70	1	1.0	1,000	298	303.1	15,900

4.4.1 General characteristics and behaviour of hake schools During the spring-fall period off the Oregon to Vancouver Island coast, hake are typically found schooled in long relatively narrow bands, with the long axis of the schools oriented parallel to isobaths. With this orientation any one school does not extend over a significant bottom depth range; usually the depth interval is less than three fm. Exceptions to this generality are schools located at the edge of the continental shelf. Schools found on or near bottom just inside the edge of the shelf are quite often aligned perpendicular to it, and extend offshore at the same depth, such that they are high off the bottom over the slope. Within the water column the vertical depth range occupied by a school is usually less than six fm; three or four fm can be considered an average figure.

Hake schools characteristically rise and disperse in the water column during evening hours. By darkness hake are located in near surface waters and schools can no longer be defined. The few attempts made to catch hake at night have not been successful. Studies of their feeding habits indicate hake are crepuscular and/or nocturnal feeders (Alton and Nelson, *ibid*). However, it is not possible to specify the relative importance of the availability of their food supply as a factor influencing their nightly vertical migration. By dawn hake have descended in the water column and are again schooled, or at least have begun to recongregate. Alton and Nelson suggest that the degree to which hake are found congregated during the day is related to the type of food which was available during their last feeding period. In general, smaller catch rates are observed when the hake have been feeding on other species of fish than when their food is euphausiids and other macroplankton. This suggests that schools become more dispersed when feeding on fish or other mobile nekton and consequently reformation of schools is relatively delayed. Fig. 4 shows typical daytime echo sounder traces of hake schools.

Observations in Port Susan, Puget Sound and off southern California have shown that the character and behaviour of schools of spawning hake differ from those of schools observed in coastal waters during the spring and summer. In Port Susan, schools which

3/ These data and those on the vertical distribution of hake in Saratoga Passage and Port Susan (Tables VI and VII) are from two vessels which used electrical depth telemetry and the same pelagic trawls throughout both fishing seasons.



Fig. 4 Echograms of schools of hake observed off Washington coast during the day

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at the peak of the spawning period form almost one continuous body of fish, are extremely dense and may be as much as 25 fm thick vertically. An echo sounder trace of a typical spawning school is shown in Fig. 5. There are distinct differences between this tracing and that typical of daytime hake concentrations in coastal waters (Fig. 4). Aside from the differences in vertical size of the school, the most prominent dissimilarity concerns the composition of the traces. That from Port Susan suggests spawning fish are densely and more uniformly spaced within the school and this is evidenced by the high catch rates routinely observed when fishing on such traces.

Although spawning schools of hake in Port Susan tend to become more diffuse and scattered as darkness approaches, pronounced vertical movement and dispersal has not been observed. There is some evidence indicating significant vertical migration of both spawning and non-spawning schools of hake in Puget Sound take place infrequently. Gill net sampling and echo sounder surveys in Saratoga Passage, which were conducted over 24 h periods during four quarters of the year, suggested hake rose off the bottom in significant quantities only during the fall period. However, these results must be qualified due to inability to control for the effects of variables other than season, location, and method of fishing.

Results of surveys off southern California indicate actively spawning hake in that region do not engage in diel vertical movements. Although schools composed of either nearly ripe or recently spawned fish were found to migrate toward the surface and disperse at night, schools of running ripe fish remained stationary.

4.4.2 Vertical distribution of hake indicated by fishing Catch and effort statistics from the simulated fishing trials of the chartered vessel WESTERN FLYER in 1965 and from the 1966 commercial fishery have been employed to indicate the frequency of occurrence and density of coastal hake in relation to depth of the bottom. In both years fishing was carried out between July and October. Only effective fishing effort i.e., hauls in which some hake were caught are included. Fishing took place almost entirely between 0600 and 1900 h Pacific Standard Time and only data from this time interval are presented.

TABLE V - Fishing effort in hours (f) and pounds of hake caught per hour (c/f) and number of trawl hauls, by depth off bottom.
Data from simulated fishing trials of chartered vessel,
WESTERN FLYER, 1965 and from the 1966 commercial fishing.

	Depth off bottom (fm)	Hauls		f		c/f
		No.	Percent	No.	Percent	
Fishing trials WESTERN FLYER, 1965	0-4	69	43.1	79.0	39.2	11,600
	5-8	53	33.1	75.6	37.5	6,400
	9 >	38	23.8	47.1	23.4	7,200
	Total	160	100.0	201.7	100.0	
Coastal hake fishery, 1966	0-4	274	71.4	357.0	73.9	7,600
	5-8	55	14.3	62.9	13.0	10,300
	9 >	55	14.3	63.4	13.1	4,900
	Total	384	100.0	483.3	100.0	
1965 and 1966 data combined	0-4	343	63.0	436.0	63.7	8,400
	5-8	108	19.9	138.5	20.2	8,100
	9 >	93	17.1	110.5	16.1	5,900
	Total	544	100.0	685.0	100.0	



Fig. 5 Echogram of school of spawning hake in Puget Sound

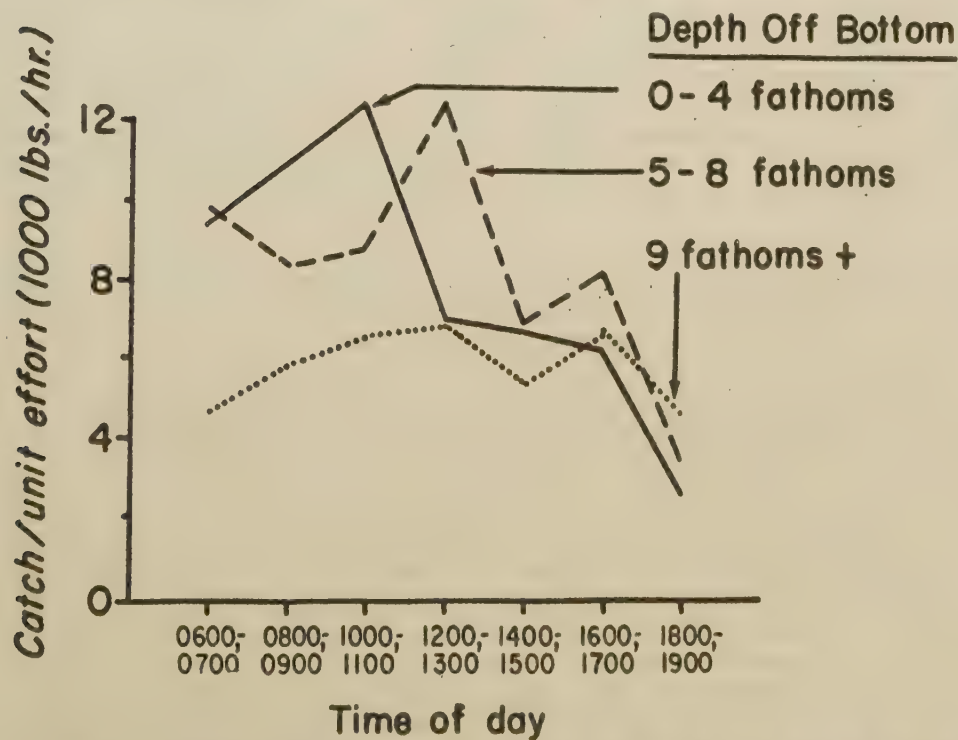


Fig. 6 Hake catch per unit of effort, by depth off bottom and time of day (Pacific Standard Time). Data from 1965 fishing trials and 1966 U. S. coastal hake fishery.

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During both years over 75 percent of the fishing effort took place within eight fm of the bottom (Table V). The concentration of fishing near bottom was especially pronounced in 1966. This agrees with survey observations indicating hake were more often located on bottom in 1966 than in previous years. This may be related to the massive Soviet fishing effort which appeared to break up large schools of hake. The results indicate hake were most abundant and more often encountered within eight fm of the bottom. The data are insufficient to attempt an explanation of the difference between the two years in the relative position of the catch rate in the zone nine fm and greater above the bottom. Theoretically, a lower catch rate could be expected in this zone regardless of any real difference in abundance. As the distance off the bottom at which the net is fished increases, the likelihood of its being avoided by fish also increases - at least during daylight hours. Furthermore, when fishing near bottom the precision with which the net is positioned is less critical than when higher in the water column. Also, when fish are located close to the bottom they have relatively less chance to avoid capture if they attempt to dive beneath the net.

The catch per unit effort data for the two years combined are plotted by off-bottom depth interval and time of day in Fig. 6. This provides a gross look at the daily trend in catch rates. No adjustment was made for changing day length. In all depth intervals the maximum catch rate occurred during midday (1100 to 1400 h) and declined steadily thereafter in the two deepest depth zones. In each depth interval the lowest rate occurred during the last period of the day. Interpretation of the observed trend is complicated since it is probable that it is partially a function of the behaviour of the fishermen and the process of scouting for fish sign. Prior to midday a substantial part of the time may often have been spent locating fish, especially if they were not available the previous day. This would tend to minimize the catch rate during the first part of the day. If good catches of fish were not made by midday, or if they were but the fishermen considered their chances for good fishing during the remainder of the day were poor, then their efficiency most likely declined as the day progressed. Also they were probably more liable to terminate fishing earlier when a large part of the day had passed without finding fish.

Despite the possible effect of these artifacts on the observed daily trend there is reason to believe that some of its more prominent features, i.e. a rising trend in catch rates prior to midday and a substantially lower catch rate just prior to night-fall reflect the true pattern of availability. The significant drop in catch rate between the periods 1600 to 1700 h and 1800 to 1900 h suggests the usual evening dispersion and vertical movement had begun to take place. A general increase in catch rate during morning hours would be expected if it is assumed reformation of hake schools is not completed rapidly early in the morning but rather occurs over a period of several hours.

Admittedly, the above discussion of vertical distribution and daily changes in abundance is largely oversimplified. However, it is pertinent that the data indicate significant changes in availability regularly occur within the daytime period.

The vertical distribution of hake in inside waters, as indicated by fishing, is shown in Table VI. As observed in the fishery off the coast, over 70 percent of the fishing effort took place within eight fm of the bottom. Maximum catch rates in Port Susan also occurred in that depth zone. In Saratoga Passage there was relatively little variation in catch rates between depth zones, but the effort data indicate schools were most frequently encountered close to the bottom. The results indicate spawning, or near-spawning hake usually gather in dense schools close to the bottom. Selected data on the diurnal trend in hake catch rates, unadjusted for changing day length, are presented in Table VII. In both Saratoga Passage and Port Susan the trend is unlike that observed in coastal waters. There is little variation in catch rates with time of day in Saratoga Passage. The same is true in Port Susan, except for the higher catch rates observed late and particularly early in the day. These high catch rates make the trend essentially opposite to that observed for coastal hake (Fig. 5).

TABLE VI - Fishing effort in hours (f) and pounds of hake caught per hour (c/f), by depth off bottom, in Saratoga Passage and Port Susan. Data for 1965 to 66 and 1966 to 67 fishing seasons combined. 4/

Area	Depth off bottom (fm)	Hauls		f		c/f
		No.	Percent	No.	Percent	
Saratoga Passage	0 - 4	122	58.6	181.8	64.5	8,200
	5 - 8	21	10.1	24.0	8.5	10,100
	9 - 12	27	13.0	33.0	11.7	9,900
	13 >	38	18.3	43.3	15.3	8,000
	Total	208	100.0	282.1	100.0	
Port Susan	6 - 4	225	65.2	260.1	63.2	16,900
	5 - 8	71	18.2	71.7	17.4	15,000
	9 - 12	36	9.2	43.7	10.6	7,600
	13 >	29	7.4	36.0	8.8	5,300
	Total	391	100.0	411.5	100.0	

It is difficult to explain why the observed diurnal trends in hake catch rates exist. As pointed out earlier, pronounced vertical movement and dispersion of hake at night apparently do not occur in Port Susan and Saratoga Passage. If it is assumed vertical migration occurs as part of the daily feeding cycle then it would not be expected to occur in Port Susan where hake are spawning, and feeding fish have not been observed. The high catch rate observed in Port Susan during the first part of the daytime period is probably due to the fact fish are consistently found clustered very close to the bottom at this time (Richard McNeely, personal communication). Why they are found especially close to the bottom early in the day, and why relatively large catch rates are observed late in the day cannot be explained. In Saratoga Passage, the few hake stomachs examined during the fall and winter period have been empty. One sample of hake taken from that area in May were feeding on euphausiids. The relative abundance of euphausiids in Saratoga Passage and their importance as a food of hake are unknown. The uniformity of catch rates with time of day tends to indicate hake do not migrate significantly at night, and possibly this is related to the abundance of macroplankton prey.

It is doubtful that artifacts resulting from the nature of the fishing operation significantly affect the diurnal trend in catch rate in either Saratoga Passage or Port Susan. Vessels operate close to port and comparatively little time is spent scouting for fish. If fish are present at all, they are quite readily located.

TABLE VII - Fishing effort in hours (f) and pounds of hake caught per hour (c/f), by time of day, in Saratoga Passage and Port Susan. Data for 1965 to 66 and 1966 to 67 seasons combined. Saratoga Passage data includes only months of November, December and January. Port Susan data includes months of January, February and March ^{5/}

SARATOGA PASSAGE		
Time of day ^{6/}	f	c/f
0600, 0700, 0800	44.3	8,100
0900, 1000	36.4	8,500
1100, 1200	34.4	9,100
1300, 1400	43.2	8,600
1500, 1600, 1700	29.5	8,300
PORT SUSAN		
Time of day ^{6/}	f	c/f
0600, 0700	48.4	20,200
0800, 0900	53.0	13,400
1000, 1100	58.7	13,700
1200, 1300	49.4	13,100
1400, 1500	63.4	14,000
1600, 1700, 1800	66.1	16,000

5 DISCUSSION

Information on the distribution, abundance, and behaviour of hake, presented in the foregoing, provides a basis for considering relationships between the availability of the stocks and the harvesting process. The relative efficiency of methods of detection and extraction, operational strategy in relation to hake behaviour and movements, and the present and future spatial and temporal distribution of fishing effort are of particular concern.

This discussion does not consider the problem of stock management. It is sufficient to note that any reasonable set of estimates of stock magnitude and population parameters suggests several hundred million lb of hake can be harvested on a sustained basis from coastal waters off western North America.

^{5/} See footnote 3
^{6/} Pacific Standard Time

5.1 Influence of gear type on harvesting efficiency

Exploration and development of the potential of the Pacific hake resource has taken place as the result of a variety of factors. Among these the successful development of the COBB pelagic trawl and electrical depth telemetry can be readily singled out as being one of the most, if not the most, important. Without an efficient mid-water trawling technique, neither investigation nor harvesting of the hake resource would have occurred.

In the foreseeable future, as at present, pelagic fishing with trawls equipped with depth telemetry will provide a large majority of U.S. hake production. Because of the extent to which they occur off bottom, efficient harvesting of hake cannot be accomplished using demersal gear. However, the proportion of time hake are found on or close to the seabed is not insignificant, and to maximize fishing efficiency a vessel should be capable of harvesting fish on as well as off bottom. Realization of the need for versatile gear has led the Bureau of Commercial Fisheries to design and construct a new net known as the Universal trawl. This is basically a pelagic trawl, modified to fish on bottom by constructing the belly of heavier webbing and by using a cable footrope. Recent utilization of the Universal trawl by most of the vessels in the U.S. hake fishery has demonstrated the value of the capacity to fish either pelagically or demersally with a single piece of gear. Because hake are often located off, but close to, the seabed, gear which can fish equally effectively on or off bottom increases the efficiency of pelagic fishing.

The feasibility of harvesting hake with other than trawl gear has not been thoroughly investigated. The schooling characteristics and depth distribution of hake are significantly different from those of clupeoid, salmonoid, or tuna-like fishes and it is unlikely that purse seining would be a practical harvesting method. However, sunken purse seines, such as those employed in Europe to catch cod, could possibly be effective in capturing hake near bottom. At present, research is being conducted to perfect gear such as the Universal trawl.

5.2 Hake behaviour and the conduct of fishing

The diel vertical migration of hake significantly influences harvesting strategy. It effectively eliminates night fishing and may curtail fishing success early and late in the day. This is true whether fishing is conducted in coastal or inside waters, even though the vertical movement and dispersion of inside stocks are less pronounced. The vertical migration and subsequent re-formation of hake schools probably accounts for a significant part of the day-to-day problem of locating fish. If fisheries are prosecuted in areas where pelagic fish may be the primary food of hake, e.g., off California, this problem may be magnified.

As indicated above, the daytime vertical distribution of hake in the water column is an important factor influencing gear design. As more data become available it will be pertinent to determine if significant changes in this distribution occur according to season, geographic area, or bottom depth.

The usual orientation of hake schools; i.e., with a long axis paralleling bottom contours, influences the choice of searching methods. Echo sounder surveys for hake are normally conducted by running offshore-onshore transects at oblique angles to the coastline, turning parallel to the coast only to determine school dimensions once fish sign is observed. This is the most efficient method of locating fish. The bathymetric range to be searched depends on season, area, and other factors.

The composition of hake schools, as indicated by echo sounder recordings, varies substantially with the density of fish, proximity to the bottom, and undoubtedly a variety of unknown factors. Although significant quantities of other species are rarely found schooling together with hake, schools of rockfish (Sebastes sp.), northern anchovy (Engraulis mordax), various smelts, and especially jellyfish (Cyanea sp.)

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may be incorrectly identified as hake. High resolution, low frequency echo sounders, properly used, contribute materially to accurate delineation of fish sign and hence the productiveness of the fishing operation. Sonar ranging does not enhance searching efficiency for non-spawning fish unless operators of the instrument are particularly skilled and can recognize fish sign close to the bottom.

Relatively small-scale bathymetric, areal, and intraseasonal changes in abundance due to movement or new recruitment, such as those noted to occur on the continental shelf and in inside waters, have definite effects on fishing success and trends in production. For example, shifts in abundance of hake along the Oregon-Vancouver Island coast during the summer significantly affect both the fisherman and the processor. After the early part of the season, the processing plant can expect less frequent deliveries and lower volume per unit time, and probably poorer quality fish. Of course, the profit margin is reduced for both the processor and fisherman as fish become less densely concentrated and/or more remote from the processing facility, which is the general tendency in the coastal hake fishery as the season progresses. The pronounced spatial and temporal change in the availability of hake in the Saratoga Passage-Port Susan area during the fishing season raises a variety of interesting and significant questions regarding the strategy of fishing. This is especially so because the fishery takes place in a small, relatively well-defined area, and it is possible to predict quite accurately the period (spawning) when fish are most vulnerable. If, in the future, it becomes possible each year to predict both the relative stability of market conditions and a schedule for the availability of gear prior to the fishing season, then it might be practical to attempt a limited analysis of the problem of optimizing economic return from the fishery.

5.3 Deployment of fishing effort in time and space

Although their relative abundance varies according to season and location, in the course of a year Pacific hake are found in substantial quantities along a 1200 mile coastal area between British Columbia and Mexico. Essentially, exploitation of hake has been confined to a 200 to 300 mile area along the Oregon-Washington coast. It is pertinent to note that significant events with regard to the history of production from the hake resource can be readily "capsulized". Large-scale production was first realized in 1966 as a result of a massive effort by Soviet nationals fishing off the Oregon-Vancouver Island coast. In 1967, using pelagic and combination pelagic-demersal trawls, U.S. fishermen began successfully harvesting hake along a limited portion of the Washington-northern Oregon coast. During the first six weeks of the fishery, eight small (three to four man) trawlers harvested 10 million lb of hake.

Since efficient harvesting gear and a preliminary knowledge of the resource's availability are now on hand, it is relevant to consider possibilities regarding expanded utilization. We will assume some degree of market expansion will take place as the result of increased demand for fish protein concentrate and animal food.

All evidence collected to date indicates the hake resource is most accessible in continental shelf waters off Washington and Oregon during the spring to fall period. Even without a significant change in market conditions, U.S. effort in this area can be expected to increase. This is because of a developing awareness of the availability of hake and their vulnerability to the new trawl gear. Most likely, and especially if there is a significant increase in the price paid for hake, more vessels will begin to enter the fishery and the fleet will eventually cover more of the shelf area between central Oregon and central Vancouver Island, rather than concentrating in the northern Oregon and Washington area. Aside from its direct effect on the industry, such fishing effort will provide the scientist with a much better understanding of the distribution and dynamics of the stock. It is doubtful that the extent of the fishing period during the year will change, or that significant effort will be devoted to harvesting hake over the continental slope. Fishing from late fall to early spring is improbable, primarily because of the availability of fish, but also because present U.S. vessels cannot operate in the adverse weather which prevails during this period.

A combination of the relatively low abundance of hake and limitations of vessels and gear dictates against significant exploitation of the slope area.

A marked north to south decrease in continental shelf area occurs between British Columbia and Mexico; particularly prominent is the lack of shelf area off southern California. The extent of the shelf area is one of the factors which will govern possible expansion of the fishery into the area south of where hake are now being harvested in quantity. Of interest is the possibility of increasing production from the central Oregon to central California region (roughly, the area between Newport, Oregon and San Francisco, California). As was shown, this area is apparently less densely populated than the area north of it. However, hake in this area are only exploited by the small California otter trawl fishery and its potential should be more thoroughly studied. Even if the abundance of hake is relatively low, if efficient gear is employed and there is a significant increase in the price of hake, substantial fisheries might develop. Of course, if exploitation in the area did increase it could have important effects on the fishery further north and knowledge of the dynamics of the stock would become particularly critical.

It is improbable that hake fishery will spread north of Vancouver Island, the effective northern limit of the species range. The possibility of harvesting spawning hake in the southern California-northern Mexico region is a question mark. Besides the need for knowledge of the behaviour, movements, and local distribution of spawning hake, it is evident that methods of aggregating spawning fish need to be developed before they can be efficiently exploited.

6 REFERENCES

- Ahlstrom, E.H., Vertical distribution of pelagic fish eggs and larvae off California
1959 and Baja California. Fishery Bull.Fish Wildl.Serv.U.S., 60(161):107-46
- Ahlstrom, E.H. and R.C. Counts, Eggs and larvae of the Pacific hake (Merluccius
1955 productus). Fishery Bull.Fish Wildl.Serv.U.S., 56(99):295-329
- Alton, M.S. and M.O. Nelson, Preliminary study on the feeding behaviour of Pacific
1967 hake in Washington and northern Oregon coastal waters. Seattle, U.S. Fish
and Wildlife Service, Bureau of Commercial Fisheries, 25 p. (Unpubl. MS)
- Alverson, D.L., A deep-water trawling survey off the coast of Washington. Comml
1951 Fish.Rev., 13(11):1-16
- _____, Deep-water trawling survey off the Oregon and Washington coasts.
1953 Comml Fish.Rev., 15(10):5-15
- _____, Trends in trawling methods and gear on the west coast of the United
1959 States. In Modern fishing gear of the world, edited by Hilmar Kristjonsson,
London, Fishing News (Books) Ltd., pp.317-20
- Alverson, D.L., A.T. Pruter and L.L. Ronholt, H.R. MacMillan lecture in fisheries.
1964 A study of demersal fishes and fisheries of the Northeastern Pacific
Ocean. Vancouver, University of British Columbia, Institute of Fisheries
190 p.
- Angelescu, V., and M.L. Fuster de Plaza, Migraciones verticales ritmicas de la
1965 merluza del sector bonaerense (Merluciidae, Merluccius hubbsi) y su
significado ecologico. An.da Acad.Brasileria de Ciencia 37:194-214
- Angelescu, V., F.S. Gneri and A. Nani, La merluza del mar Argentino (biologia y
1958 taxonomia). Publnes Serv.hidrogr.nav., (H.1004):224 p.
- Best, E.A., Contribution to the biology of the Pacific hake, Merluccius productus
1963 (Ayres). Rep.Calif.coop.oceanic Fish.Invest., 9:51-6

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- Brunel, P., Food as a factor or indicator of vertical migrations of cod in the
1965 western Gulf of St. Lawrence. Spec.Publs int.Commn NW.Atlant.Fish.,
(6):439-48
- Clemens, W.A., and G.V. Wilby, Fishes of the Pacific coast of Canada. Bull.Fish.Res.
1961 Bd Can., (68):443 p.
- DeWitt, Jr., J.W., An occurrence of the natural destruction of hake in Humboldt
1952 County. Calif.Fish Game, 38(3):438
- Dodimead, A.J., F. Favorite and T. Hirano, Salmon of the North Pacific Ocean. Part 2.
1963 Review of oceanography of the subarctic region. Bull.int.N.Pacif.Fish.
Commn, (13):195 p.
- FAO/UN, Informe al gobierno de Chile sobre investigaciones biologicas acerca de
1952 los peces alimenticios de Chile con la referencia especial a la merluza.
Rep.FAO/EPTA, (45):72 p.
- Hanson, H.C., Pacific combination fishing vessels. In Fishing boats of the world,
1955 edited by Jan-Olof Traung, London, Fishing News (Books) Ltd., pp. 187-202
- Hickling, C.F., The natural history of the hake. Fishery Invest.,Lond.(2),
1927 10(2):100 p.
- _____, The natural history of the hake. Fishery Invest.,Lond.(2),
1933 13(2):120 p.
- Hipkins, F.W., Midwater trawl, telemetry gear prove value on Puget Sound hake.
1966 Natn.Fisherm., November issue
- Larkins, H.A., H.H. Shippen and K.D. Waldron, Features of a northern Puget Sound
1967 hake population. Seattle, U.S. Fish and Wildlife Service, Bureau of
Commercial Fisheries, 19 p. (Unpubl. MS)
- Lusz, L.D., An improved depth telemetry system for fishing gear experiments. Trans.
1965 Ocean.Sci.Eng.Conf., 1965:759-70
- McNeely, R.L., L.J. Johnson and C.D. Gill, Construction and operation of the COBB
1965 pelagic trawl (1964). Comml Fish.Rev., 27(10):10-7
- Morgan, A.R. and D.E. Gates, A cooperative study of shrimp and incidental fish
1961 catches taken in shrimp fishing gear in California and Oregon, 1958.
Bull.Pacif.mar.Fish.Commn, (5):85-106
- Starks, E.C., and E.L. Morris, The marine fishes of southern California. Univ.
1907 Calif.Publs Zool., 3(11):159-251
- Wathne, F., Pacific coast drum trawling. Comml Fish.Rev., 21(12):34-6
1959
- Anonymous, Brief review of scientific research carried out by TINRO in the Vancouver-
1966 Oregon area. 29 p. (Unpubl. MS)

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OBSERVATIONS ON THE BEHAVIOUR OF FISH DURING CAPTURE BY THE
DANISH SEINE NET, AND THEIR RELATION TO HERDING BY TRAWL BRIDLES

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Abstract

The reaction of plaice, haddock and gurnards to the advancing ropes and netting of a Danish seine was watched by divers. The reaction distance of plaice was usually from 0.5 to 1.0 m and they swam at right angles to the ropes and settled until the rope reached them again. Haddock were not seen during herding but often appeared suddenly in the net mouth in large numbers and kept station between the wings. Gurnards when herded also swam away from the ropes in short bursts but their direction of swimming was more random; they also kept station with the netting but tended to keep further from it. The importance of the wings in herding was demonstrated by removing the rear part of the net leaving only the wings and adjacent areas; haddock were then still "held" by the netting on either side. The late stages of hauling, as the wings close, are extremely critical as fish in front of the net may build up and spill over the headline as their density increases beyond a threshold level. A theoretical consideration of stamina of haddock and the herding efficiency of bridles at different angles of attack shows that significant effects may be possible by making small changes in towing speed or net configuration. Not only must the herding stimulus be adequate to keep the fish inside the bridle, but also it must not be so great that the fish is exhausted before reaching the path of the oncoming net.

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OBSERVATIONS SUR LE COMPORTEMENT DES POISSONS DURANT
LEUR CAPTURE PAR UNE SENNE DANOISE ET SUR L'EFFET DE
RASSEMBLEMENT DETERMINE PAR LES CORDES

Résumé

Des plongeurs ont observé la réaction de plies, d'églefins et de grondins à l'approche des cordes et du filet d'une senne danoise. C'est généralement lorsque la corde est à 0,50-1 m que les plies s'en éloignent, en nageant perpendiculairement à celle-ci, pour se poser plus loin jusqu'à ce que la corde s'approche de nouveau. On n'a pas observé d'églefins dans les rassemblements causés par le mouvement de l'engin, mais ces poissons sont souvent apparus soudainement en grand nombre dans la gueule du filet, se maintenant entre les ailes. Lors du rassemblement, les grondins s'enfuient également devant les cordes, par brefs bonds, mais la direction de leur nage est moins régulière; ils se maintiennent eux aussi à une distance constante des nappes de filet, mais plus loin. On a mis en évidence le rôle important des ailes dans le rassemblement du poisson en retirant la partie arrière du filet, ne laissant subsister que les ailes et les parties adjacentes: les églefins continuaient dans ce cas d'être "retenus" entre les deux nappes de filet. Les derniers stades du relevage lorsqu'on ferme les ailes, sont extrêmement critique, la masse de poissons située devant le filet pouvant "déborder" par dessus la ralingue supérieure lorsque sa densité dépasse un certain niveau. Une étude théorique de la résistance de l'églefin et de la capacité des cordes en matière de rassemblement du poisson pour divers angles d'attaque révèle qu'il est possible d'obtenir des effets notables en modifiant légèrement la vitesse de remorquage ou le dessin du filet. Le stimulus de rassemblement doit non seulement être suffisant pour maintenir les poissons entre les cordes, mais ne pas atteindre une intensité telle que le poisson soit épuisé avant d'être rabattu sur la trajectoire du filet.

OBSERVACIONES SOBRE EL COMPORTAMIENTO DE LOS PECES DURANTE SU
CAPTURA CON RED DE CERCO DANESA, Y SU RELACION CON EL
AGRUPAMIENTO DETERMINADO POR LAS MALLITAS DE LA RED

Extracto

Mediante buceadores se observaron la reacción de las sollas, eglefinos y rubios (*Trigla*) al avance de las malletas y la red de un arte de cerco danés. La distancia a que reaccionaban las sollas fue, por lo general, de 0,5 a 1,0 m, nadando en ángulo recto a los cabos de la red y permaneciendo inmóviles hasta que dichos cabos llegaban de nuevo a ellas. No se vieron eglefinos durante el agrupamiento pero a menudo aparecían de repente en gran número en la boca de la red manteniéndose alineados entre las alas. Los rubios, cuando se empezaba el encauzamiento, se alejaban también de los cabos de la red mediante cortos impulsos, pero al nadar su dirección era más irregular; se mantenían también alineados con la red pero tendían a mantenerse más alejados de ella. La importancia de las alas para el agrupamiento de los peces se demostró quitando la parte posterior de la red y dejando solamente las alas y las partes adyacentes; entonces los paños de la red "mantenían" a los eglefinos a distancia en cada uno de sus lados. Las últimas fases del halado del arte a medida que se cierran las alas de éste, son muy críticas, ya que los peces que están frente a la red pueden acumularse y saltar por encima de la relinga superior cuando su densidad pasa de un nivel determinado. Una consideración teórica de la capacidad de resistencia de los eglefinos y de la eficiencia del agrupamiento logrado con las malletas en diferentes ángulos de incidencia indica que son posibles efectos importantes realizando pequeños cambios en la velocidad de arrastre o en la configuración de la red. No sólo el estímulo de agrupamiento debe ser adecuado para mantener a los peces dentro de las malletas sino que tampoco debe ser tan grande que haga que los peces se agoten antes de ponerse en el camino que sigue la red en su avance hacia ellos.

1 INTRODUCTION

The experience upon which this paper is based derives from two separate diving programs in different circumstances: firstly observation of the Danish seine net in the Moray Firth (N.E. Scotland) described briefly by Parrish *et al.* (1964), and secondly observations on model and full-sized trawls off Corsica during the joint international program arranged by the I.F. group in May/June 1966. The paper describes the behaviour of haddock, flatfish and gurnards in the process of capture by the Danish seine and then attempts to relate this observed behaviour to the probable conditions expected in the mouth of a trawl. This work is a sequel to that carried out at Aberdeen during which the late Lt. Cmdr. J.H. Hodges made the film "Fish and the Seine Net".

2 METHODS

The technique common to both programs mentioned was direct observation with the use of self-contained breathing apparatus. The method of fishing the Danish seine was similar to that in current practice in Scotland (see Dickson, 1959) except that the length of each rope was only four coils (approximately 875 m) and fishing was confined to areas of 30 m depth or less, usually over a sandy bottom. This enabled the complete fishing procedure to be observed within the time of one dive (25 to 35 min). Underwater visibility was usually 3 to 8 m, and the behaviour of the fish was assumed to be largely modified by vision.

The Danish seine consists of a long-winged net which, at the commencement of fishing, is stretched straight out normal to the line of advance. As the ropes are winched in to the ship, it moves forwards with gradually increasing speed, the net taking up a catenary of increasing curvature until at the last stages of hauling the wings lie parallel, along the line of advance. For convenience of description the change of shape of the net is broken into stages as shown in Fig. 1. The usual Scottish fishing practice is to increase slightly the speed of hauling during stages A to E, and then, when it is assumed that the net is closed and fishing is complete, the speed is abruptly increased to about 3 kn (1.5 m/sec) for the recovery phase, referred to as fast hauling. This procedure was followed during experimental hauls.

During underwater observation hauls, a float was attached to the middle of the headline by 40 m of light synthetic rope. Just before hauling commenced, divers descended this rope and located and hung on to the net usually somewhere along the headline. From this point, close observation could be made of the behaviour of fish in the vicinity of the groundrope and the side walls of the net. On a number of occasions, observations were made of herding by the seine net ropes. In the early slow stages this was achieved by divers swimming along behind the rope, but as the speed increased they hung on to it; this did not change its shape or distance off the bottom.

3 RESULTS

The most striking observation was the absence of any behaviour that could be regarded in any respect as "panic-stricken". The swimming of fish of all species observed with the exception of mackerel appeared to be quite natural. Mackerel were only encountered in a few hauls and few were caught, but at all stages they showed a pattern of violent swimming in different directions, usually leading to their escape.

3.1 Flatfish

Flatfish, mostly plaice, Pleuronectes platessa L., but also some dabs, Limanda limanda L., were very common on the grounds fished. They were noticed in front of the groundline at all stages of hauling, the numbers gradually increasing as the haul progressed. The distance from the ropes at which they commenced swimming varied from zero (when fish were actually touched by the rope) to 3 m, but the reaction distance of most was between 0.5 and 1.0 m. A certain number remained stationary and thus escaped under the rope. Those that reacted as far away as 3 m probably were stimulated to swim by other fish swimming near them. The fish usually swam off to about 3 to 5 m distance and then



FLATFISH

GURNARDS

Fig. 2 Direction of swimming of the flatfish and gurnards to an approaching seine net rope or groundrope.

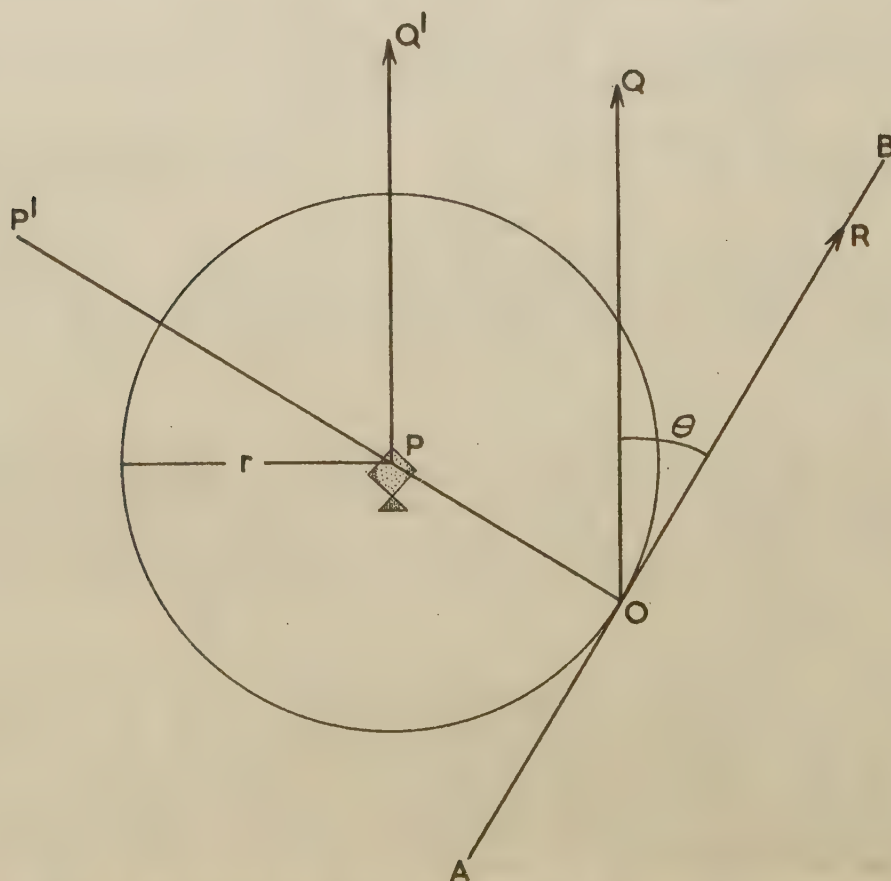


Fig. 3 Situation when a flatfish at point P responds at a distance r from a rope AB moving in direction OQ with angle of attack θ (see text for further details).

settled again on the bottom. As shown in Fig. 2 the direction in which they swam was not away from the gear in the direction in which it was moving, but most typically at right angles to the approaching seine net rope and groundrope. The result was that by this zigzag process of reacting to the rope and settling until it caught up with them, the flatfish gradually accumulated in the net bight. Here they swam, presumably until fatigued, when they fell back over the groundrope into the funnel of the net.

3.2 Haddock

Haddock were not observed, at any stage, being herded by the ropes during the haul, and during observation from the headline they did not usually appear until stage C or D when the front of the net at the limit of visibility appeared quite suddenly to be nearly full of them. They soon fell back and filled the net mouth. On one haul only was a school of small haddock (15 to 20 cm) encountered in the net mouth during stage A. The work of Blaxter and Parrish (1966) provides evidence that haddock are herded effectively by a simple rope. These observations imply that haddock occurred in one or more schools distributed in the area fished, and that these were then herded into the path of the net by the seine net ropes. This could account for the failure of haddock to appear until stage C or D of the fishing process. When in the net mouth the haddock swam in the same direction and at the same speed as the net. The impression given was of fish maintaining station between the wings, rather as freshwater fish maintain station in a stream. When only few fish were present, they remained close to the sea-bed extending forwards from the groundrope. In those hauls where there were large numbers of fish, they extended forwards towards the wing ends and also built up in height. On some occasions, as the two wings approached each other during stages E and F, the height of the mass of fish rose to the height of the headline. This naturally resulted in the escape of some of them over the headline. The individual fish in the mass occupying the net mouth appeared not to tolerate being packed beyond a specific "density" and thus the mass of fish could be described as being squeezed over the headline by the approaching wings. During stages C, D and E before fast hauling commenced, only comparatively few fish passed back over the groundrope, commonly as individuals, but sometimes rather larger groups of up to ten fish. One characteristic behaviour pattern was that once over the groundrope, the fish turned and swam towards the approaching codend. At the commencement of fast hauling, the fish kept up with the sudden increase in speed for a few seconds but then rapidly passed back into the net. It seems likely that with the longer seine net ropes used commercially a higher proportion of the fish will become fatigued and fall back into the net before the commencement of fast haul, than in this small-scale experiment. The occurrence of a mass of fish in front of the groundrope at the end of the slow haul period in a commercial operation thus depends upon the probability of the school of fish being in that part of the sea-bed that is swept during the final stages of slow hauling before the fish become exhausted.

On two hauls the whole rear funnel of the net had been cut off, leaving only the wings and adjacent areas surrounding a large hole. If, in the normal way, fish are induced to swim, or even hydrodynamically "pushed" through the water by the net behind them, then one would not have expected the fish to swim between the wings in the absence of the remainder of the net. However, in these experiments there was no apparent difference in the behaviour of the fish, just as many being held between the two wings as when a complete net was fished. At the commencement of fast haul when the fish would have entered the funnel of the net, they passed back through the hole and swam away.

3.3 Gurnards

Varying numbers of gurnards were caught in nearly all hauls. They were seen at all stages of the haul, suggesting that they were quite widely dispersed although they were often seen in groups of perhaps six to eight fish. Their reaction was similar to that of the flatfish in that they swam away from the approaching ropes and net and then settled again for a short while. In contrast to the flatfish, the direction of swimming was apparently much more random, as shown in Fig. 2. Despite this, considerable numbers accumulated in the centre of the net bight during stages A, B, C and D by a similar zig-

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zag process. When gurnards were frequent on the fishing ground, which commonly coincided with a shortage of haddock, the most striking aspect of their behaviour was seen. In stages D and E, there extended forwards from this central mass in the net mouth, a narrow column of fish. This column was never more than one or two fish deep and three or four fish wide, but extended as far forward as the observers could see. The speed of these fish was slightly less than that of the net and they gradually fell back into the main group. The strong impression was gained that the fish were holding station between the two wings in exactly the same way as the haddock, but that the gurnards were trying to avoid each wing as far as possible, by remaining in the mid-line of the net.

The capture process is probably also due to fatigue as fish gradually pass back over the groundrope, but as with the flatfish, many gurnards pass under the groundrope.

4 DISCUSSION OF RESULTS

In the relatively clear water conditions in which the seine net observations were carried out, it has been assumed that the behaviour of the fish was primarily governed by visual stimuli. A discussion of the relationship between all the senses possibly involved in fish capture is given elsewhere in this symposium. The two most interesting and significant aspects of behaviour in the fishing process are firstly that of herding by the seine net ropes and secondly that of the behaviour of fish in the mouth of the net.

4.1 Herding

It was unfortunate that the only fish regularly observed in large numbers being herded by the seine net ropes were flatfish, and smaller numbers of gurnards. In discussing the results of flatfish there are a number of implications of more general interest. Fig. 3 shows a flatfish on the bottom at point P with a "reaction distance", assumed to be circular of radius "r".^{1/} A line A B representing the rope moving in direction O Q is shown at the reaction distance from the fish, i.e. when O P equals r. O P is one component of the two into which the forward movement represented by the vector O Q, can be resolved; the other being O R along the rope. The ratio between O P and O Q is dependent upon the angle of attack = θ of the rope A B:

$$\text{Sine } \theta = \frac{O P}{O Q}$$

The observed movement of the fish is not in the direction of travel of the rope P Q', but in the direction P P'. There are two possible explanations why the fish moves from P towards P' rather than towards Q'. Firstly, that part of the rope A B nearest to the fish situated at P will always be on the line O P, even though the rope is actually moving in the direction O Q. Thus the fish swims directly away from the part of the rope nearest to it. The second possibility depends upon the visual acuity of the fish eye. To know the real direction of movement O Q, of an oblique moving line such as A B, the eye at P must be able to determine the component O R as well as the component O P towards it. Thus if the visual acuity of the flatfish eye is too poor to perceive the lay or twist of the seine net rope, it cannot detect the true direction of movement and the fish will swim away from P towards P', that is opposite to the only component that its eye can perceive. It should be noticed that perpendicular orientation is physiologically the most economical in that it requires the least expenditure of energy necessary to escape the rope. Further discussion of herding by the ropes is left until the next section, in which the implications of these results are considered in connection with herding by the bridles of the Vigneron-Dahl gear of trawls.

^{1/} Many fish can see very nearly all round themselves and the flatfish can see a complete hemisphere, therefore the assumption of a circle is not too arbitrary. The reaction distance will depend upon the "detection distance" which in this case is the visible distance of the rope, minus the distance that the stimulus moves during the fish's reaction time. Possibly also the fish may tolerate the approach of the stimulus closer than the maximum visible distance before reacting to it by swimming away.

4.2 Behaviour in the mouth of the net

The behaviour of fish in the mouth of the net appears from the results to be essentially a visual phenomenon. It is suggested that this is an example of the optomotor or pseudo-rheotropic response that is quite common in fish. The haddock and, to a lesser extent, the gurnard appear to be forming a visual fix on the wings of the net and maintaining station against the apparent "current" caused by the motion of the wings through the water. One interesting problem set by this explanation is why a demersal fish such as haddock should respond more to the visual field on either side of itself, rather than the bottom which is "moving" in the same direction as the water, relative to the wings of the net. It may be that when fishing over smooth sand as in the experimental situation, the bottom is too featureless and thus lacks sufficient luminance contrast to be visually significant. If this is the case, it follows that variation in catch on different types of ground might be due to changes in behaviour as much as to changes in abundance of fish. It is interesting to consider what could be the natural stimulus situation in which a haddock might show the optomotor response that they appear to show in the net. About the only possibility is that of a strong current or tide passing through a steep-sided gully exactly similar to the freshwater stream situation, but of course in neither of these natural cases is there relative movement between the visual field underneath and to each side of the fish.

4.3 Practical applications

These results have a number of implications as far as actual seine-net fishing operation is concerned. Firstly, it is clear that fishing has not finished when the net is nearly closed just before fast hauling begins. Fishing only ceases after perhaps 10 to 20 sec of fast hauling, which is often regarded as merely a recovery process. The occurrence of fish loss by squeezing over the headline suggests that the advantage of a high headline in a seine net is to allow a higher stack of fish to build up before this loss by squeezing begins to happen. A further improvement would be to commence fast hauling just before the net is judged to be closed, before loss of fish begins. In normal commercial operations the use of much longer seine net ropes probably means that those fish herded into the path of the net at early stages of slow hauling have tired and fallen back into the net before this squeezing could occur. However, if a large school of fish was herded during the last stages of slow haul, the situation might be exactly the same as in the experiments described above.

In the conditions in which these experiments were performed and with the net used, the behaviour of the fish did not appear to be much affected by the shape and size of the net behind the groundrope and headline. The fact that the whole of the back part of the net could be cut off without affecting the behaviour of the fish in the mouth implies that the wings are much more important. If it is judged desirable to induce the optomotor behaviour to the full, in as wide a range of water types as possible, then the wings should be made up of patches or stripes of black and white netting to present maximum contrast irrespective of the luminance of the water background.

5 DISCUSSION OF HERDING BY SEINE NET ROPES AND TRAWL BRIDLES

The experience upon which this discussion is based derives from the experiments on the Danish seine net described above, from a limited number of dives in a wet, towed underwater vehicle, observing trawls in Scottish waters, and from participation in the gear program in Corsica during 1966.

Seine net ropes and trawl bridles have one significant and basic feature in common, in that both involve an oblique rope or wire moving forwards through the water fairly close to the bottom, its function in each case being to drive fish forwards and inwards so that they enter the area subsequently swept by the net. The arguments and analysis below are developed from the observed facts, in order to define the measurements of fish reactions that should be made to determine the herding efficiency of trawl bridles of various lengths and angles of attack.

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The starting point of the analysis is the fish at P in Fig. 3, with an oblique line A B, representing the trawl bridle or seine net rope, approaching it. When A B meets the circle of radius r (the "reaction distance") there are two possibilities: either the fish swims away from this line or it fails to react, is overtaken and must be presumed to be lost to the fishing process. Those fish that commence swimming either move at a speed that keeps them a more or less constant distance from the line A B, or alternatively they may move more rapidly away from the line and then slow down or even stop until disturbed by a part of the line further back (nearer to the wing end of the net). The observed behaviour of the flatfish is the extreme case where they actually settle on the bottom until disturbed again. The majority of species probably swim at slightly irregular speed, thus coming somewhere in between these two limits. Considering the extreme case of the flatfish first, the movement shown in Fig. 4 can be analysed to reveal the significant parameters. Firstly, it must be pointed out that the movement of the fish, which can be described as zigzag relative to the line A O, is in fact a straight line over the ground O K, but broken into separate bouts of swimming activity after contact with the line.

Herding efficiency depends upon the following:

1. Probability of reaction to the line A O, assumed the same on each occasion contact is made = P.
2. Number of contacts between fish and line = C.

Therefore, herding efficiency = P^C .

In Fig. 4

$$C = \frac{l \sin \theta}{X}$$

Where θ = Angle of attack
 l = Length of line A O
 X = Distance swum when disturbed

Therefore herding efficiency = $P \frac{l \sin \theta}{X}$

An example is shown in Fig. 4. A total of N fish is contained in a square of side $l \sin \theta$. This square can be divided up into a series of strips as shown, the width of each being determined by the number of contacts made by the fish, which is in turn governed by X. If it is assumed that the fish are randomly distributed in the square then:

$$\text{Side of square} = l \sin \theta$$

$$\text{No. of fish in square} = N$$

$$\text{No. of fish per strip} = N/C$$

If one considers the case of $P = 0.5$, then the number of fish passing to the left of the square, i.e. successfully herded will be:

$$0.5 \times N/C \text{ from strip 1}$$

$$0.25 \times N/C \text{ from strip 2}$$

$$0.125 \times N/C \text{ from strip 3}$$

etc.

$$\begin{aligned} \text{i.e. number herded} &= N/C \cdot (P + P^2 + P^3 + P^4 + P^5 \dots P^C) \\ &= N/C \cdot P \left(\frac{1 - P^C}{1 - P} \right) \end{aligned}$$

From this consideration, it is clear what parameters must be measured in practice if the herding efficiency of the rope or wire is to be related to the behaviour of the fish. These are as follows:

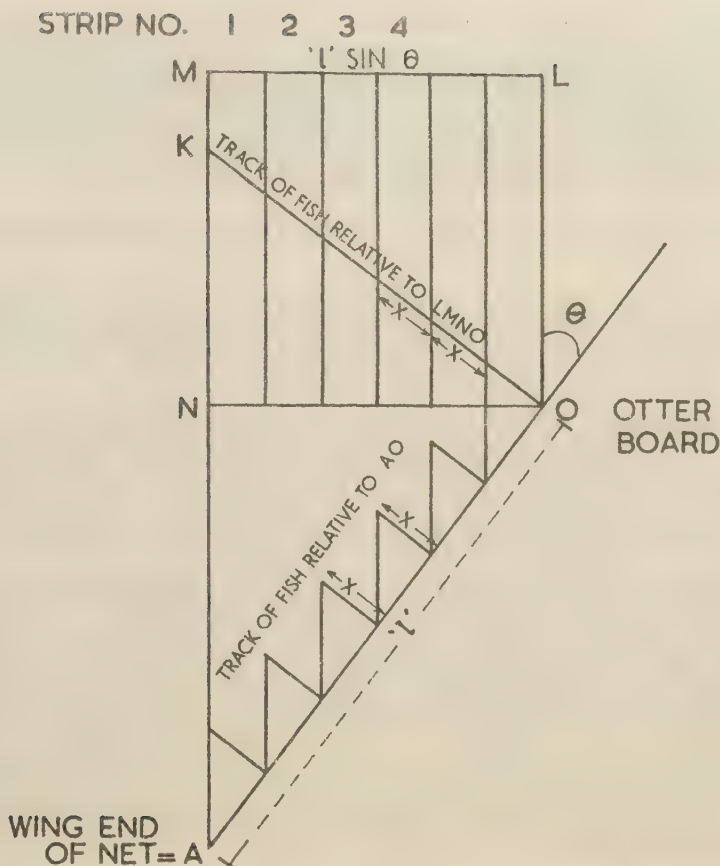


Fig. 4 Situation developed from Fig. 3 showing actual stepwise movement of a flatfish over the bottom (OK) and corresponding movements relative to the rope AO. Each step (distance swum when disturbed) is of length X (see text for further details)

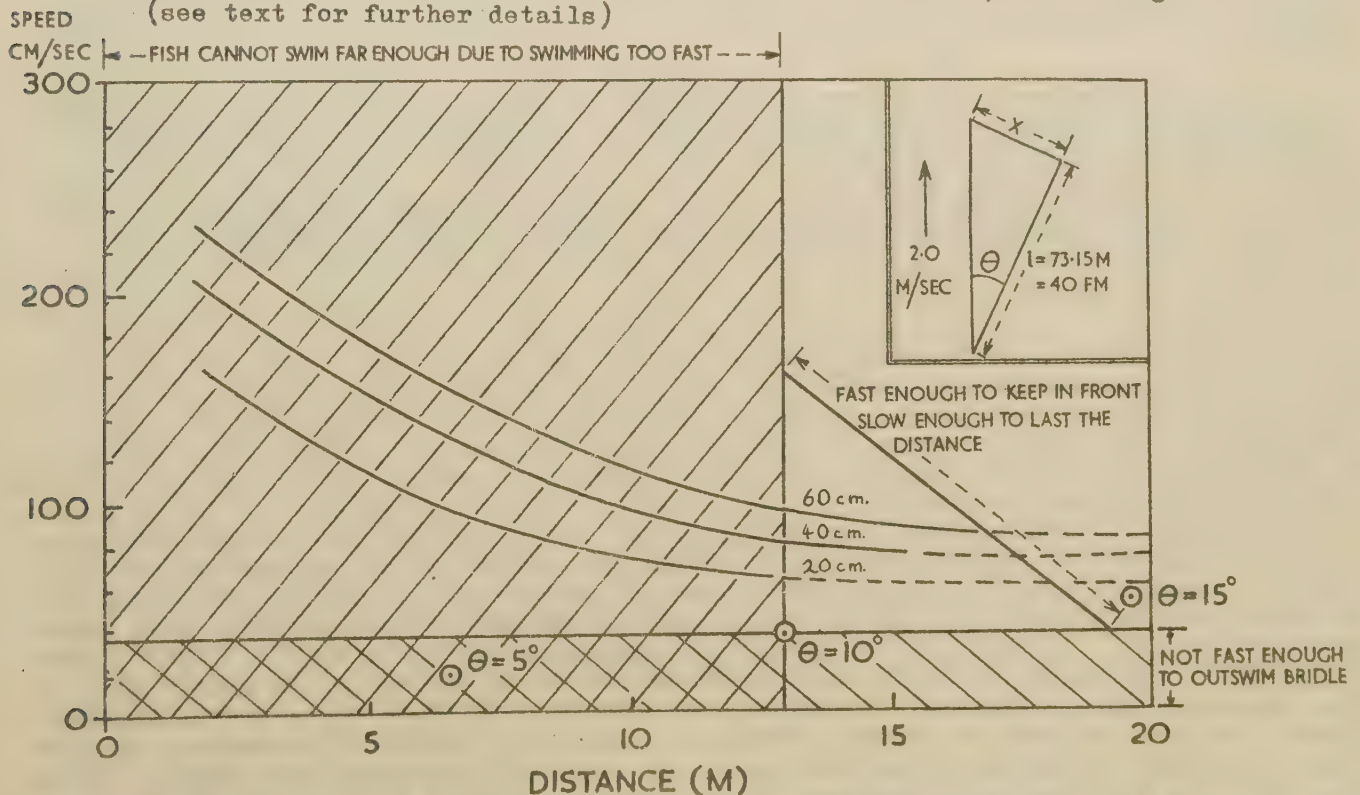


Fig. 5 Graph showing distances swum by three sizes of haddock at different speeds before exhaustion, and various theoretical situations applicable to the fish when presented with a net (see text)

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1. P, the probability of herding, measured by counting the proportion of the total number of fish that react to the rope. In all except the limiting case of the fish maintaining a constant distance, multiple contacts can be assumed to occur, therefore it should be established whether the value of P is constant for repeated contacts, by counting the proportion reacting close to the otterboard and again near the wing end.
2. The direction in which the fish react to the wire in relation to its angle of attack.
3. X, the distance swum by the fish before settling or slowing down. This is important as it determines the number of contacts along the whole length of the wire.

In the other limiting case when the fish is assumed to remain at a constant distance from the approaching line A O, herding efficiency depends upon the immediate response to the wire (P) and the occurrence of a continued reaction to it. It is probably the case that with increasing fatigue the tendency to continue swimming in front decreases. Bainbridge (1960) has provided the most useful data on speed and stamina in fish, but unfortunately his results are for three freshwater species (Leuciscus leuciscus, the dace; Carassius auratus, the goldfish and Salmo irideus, the trout). His results are expressed as the time that a fish can sustain a particular speed before exhaustion, and they clearly show that high speeds can only be maintained for a second or two, but that lower speeds can be sustained for longer times. The curves reach asymptotes equal to the steady state "cruising speed" at about 3 to 4 L/second (where L equals body length). Bainbridge continues "The rest of the curve represents potential available for a burst of swimming. This potential may perhaps be expressed in length-second units of which about twenty appear to be available. These can be expended quickly or slowly according to the degree of motivation."

This is an exceedingly important concept in considering herding. Clearly a fish highly motivated at the outer end of the trawl bridle may swim to exhaustion and be overtaken by the middle of the bridle, whereas had it swum more slowly it could have continued swimming and remained in front until it found itself inside the wing end of the net.

Blaxter and Dickson (1959) have provided data on the swimming speed of some commercially important species of fish, but unfortunately the experimental method used was entirely different from that of Bainbridge and this resulted in the presentation of results in a different form which makes comparison difficult. However, an attempt has been made to express Blaxter and Dickson's data in the form used by Bainbridge. Fig. 5 shows the distances that three sizes of haddock (20, 40 and 60 cm) might swim at different speeds before exhaustion. The graph clearly shows that the faster the fish swims the shorter is the distance it can maintain. Thus there must be a critical range of swimming speeds that result in a fish being herded into the path of the net by the bridles without reaching exhaustion first. Figure 5 shows this speed range for 73.15 m (40 fm) bridles travelling at 2.0 m/sec at angles of attack $\theta = 5^\circ, 10^\circ$ and 15° . A number of assumptions have been made, firstly that the fish is disturbed by the otterboard, and secondly that it swims at right angles to the length of the bridle, along the path X (shown inset in Fig. 5). The two variables dependent upon θ are the distance X and the speed of the component of forward motion in the same direction. These points are marked on the graph for the three values of θ . Through each point representing an angle of attack can be drawn two lines to define the limits of the "successful herding speeds"; these must be drawn parallel to the "x" and "y" axes. Only in that part of the speed/endurance curve that falls in the upper right sector thus produced will herding be successful. On Fig. 5, the lines have been drawn in for $\theta = 10^\circ$. Figure 5 also implies that the larger fish have a better chance of being herded in the simple case under consideration. However, it may well be that at some other stage of the fishing process, larger fish have an escape advantage. Again the important parameters are the initial response to the bridle and the speed and angle of movement of the fish. It is clear how very important are speed and stamina in this problem and many more data are

required on these subjects before a complete understanding can be gained of herding efficiency. The final point that must be remembered is that all the discussion above has been concerned with two-dimensional reactions, whereas the depth distribution even of a bottom-living fish cannot be ignored and so, for demersal and especially for pelagic species, the whole problem must be considered in three dimensions.

6 CONCLUSIONS

The results of this work permit suggestions to be made concerning the elements of behaviour that must be defined and measured in order to explain herding of fish in any particular context. The first of these is the most interesting from a behavioural point of view; it is to know the probability of response by the fish to the approaching rope or wire, and inseparably linked with this is to know the sensory modality involved in detecting its presence. Assuming that the reaction of the fish is to swim away from the rope or wire, the direction and distance swum and the speed of swimming of individual fish must be known. To make any sense of this a substantial background knowledge of the speed and stamina of fish must be obtained.

The final point is that all the above patterns of behaviour that must be measured vary with changes in the internal and external environment of the fish. Thus a more complete knowledge of behaviour, sufficiently accurate for predicting reactions and movement with respect to fishing gear must involve more research into the ecological and physiological aspects of the behaviour of different species.

7 REFERENCES

- Bainbridge, R., Speed and stamina in three fish. J.exp.Biol., 37(1):129-53
1959
- Blaxter, J.H.S. and W. Dickson, Observations on the swimming speeds of fish. J.Cons.
1959 perm.int.Explor.Mer, 24(3):472-9
- Blaxter, J.H.S. and B.B. Parrish, The reaction of marine fish to moving netting and
1966 other devices in tanks. Mar.Res., 1966 (1):3-15
- Dickson, W., The use of the Danish seine net. In Modern fishing gear of the world,
1959 edited by H. Kristjonsson, London, Fishing News (Books) Ltd., pp. 375-87
- Parrish, B.B., et al., Further observations by frogmen on the reactions of fish to the
1964 seine net. ICES, CM 1964, Comparative Fishing Committee (134)

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A DISCUSSION OF THE PRINCIPLES OF OBSERVING FISH BEHAVIOUR IN RELATION TO FISHING GEAR

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Abstract

Information transfer occurring during observation of fish behaviour is primarily accomplished by means of acoustic and radiant energy. In the ideal situation the observer or recording apparatus should not be perceived by the fish but in the actual situation this condition is seldom achieved. In those instances where observations are made on the behaviour of fish to a trawl the observer and net form a part of the total environmental stimulus. The trawl itself generates a complex variety of optical and acoustic stimuli to which the fish may respond. The gear technologist is concerned with what the fish will do when they encounter a particular fishing device. Behaviour of fish to fishing gear (stimuli) must be evaluated in terms of their critical threshold of detection by the involved sense organ and reaction to the stimulus. To obtain a complete knowledge of animal behaviour the biologist must at some stage become concerned with performance of individual sensory systems and single sensory cells but it is not possible to get down to that level in field studies. Of the several observation systems available the image forming optical techniques give more information than acoustic techniques but advantages and disadvantages exist for each and either or both may be employed to study fish behaviour.

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LES PRINCIPES DE L'OBSERVATION DU COMPORTEMENT DU POISSON EN FONCTION DES ENGINS DE PECHE

Résumé

L'information recueillie durant l'observation du comportement du poisson est transmise principalement par le biais de l'énergie sonore ou de rayonnement. Idéalement, l'observateur ou l'appareil enregistreur ne doit pas être perçu par le poisson, mais cette condition est rarement réalisée dans la pratique. Lorsque des observations sont effectuées sur le comportement du poisson devant un chalut, l'observateur et le filet font partie du stimulus global. Le chalut lui-même engendre un ensemble complexe de stimuli optiques et acoustiques auxquels le poisson peut répondre. Le technologue s'intéresse à ce que fait le poisson lorsqu'il se trouve devant un certain engin de pêche. Le comportement du poisson devant les engins de pêche (stimuli) doit être évalué en fonction de leur seuil critique de détection par l'organe sensoriel en cause et de la réaction au stimulus. Pour connaître à fond le comportement animal, le biologiste doit à un moment donné s'intéresser au fonctionnement des systèmes sensoriels individuels et des cellules sensorielles isolées, mais il n'est pas possible de descendre à ce niveau dans les travaux sur le terrain. Parmi les divers systèmes d'observation dont on dispose, les techniques optiques produisant une image fournissent plus d'informations que les techniques acoustiques, mais les deux méthodes présentent des avantages et des inconvénients, et l'on peut faire appel à l'une ou à l'autre, ou aux deux, pour étudier le comportement du poisson.

EXAMEN DE LOS PRINCIPIOS APLICABLES A LA OBSERVACION DEL COMPORTAMIENTO DE LOS PECES EN RELACION CON LOS ARTES DE PESCA

Extracto

El envío de la información obtenida durante la observación del comportamiento de los peces se realiza fundamentalmente por medio de energía acústica y radiante. En la situación ideal, el observador o el aparato registrador no debe ser percibido por los peces pero en la práctica esta condición se cumple pocas veces. Cuando se hacen observaciones sobre el comportamiento de los peces ante la red de arrastre, el observador y la red forman parte de todo el estímulo ambiental. El arte mismo produce una compleja variedad de estímulos ópticos y acústicos a la que el pez puede responder. El tecnólogo en artes de pesca se ocupa de lo que harán los peces cuando encuentren un determinado arte. La reacción de los peces ante los artes de pesca (estímulos) se debe evaluar en términos de su umbral crítico de detección por el órgano de los sentidos afectado y por la reacción al estímulo. Para obtener un conocimiento completo del comportamiento animal, el biólogo debe ocuparse, en cierta fase de su actuación, del funcionamiento de los distintos sistemas sensoriales y de las células sensoriales, pero en los estudios de campo no es posible descender a dicho nivel. De los varios sistemas de observación existentes, las técnicas ópticas de formación de la imagen proporcionan más información que las técnicas acústicas, pero cada una de ellas tiene ventajas e inconvenientes y se pueden emplear una u otra, o ambas, para el estudio del comportamiento de los peces.

1 INTRODUCTION

It is not the intention of this paper to provide a review of the performance of the various tools available for the study of fish behaviour at sea. Instead, the author considers some of the available and desirable techniques of observing and recording from the point of view of a behavioural biologist. These methods will be related partly to the sensory physiology of the fish, and partly to the fishing gear as the stimulus to which the fish are responding during capture processes. Most attention will be focussed upon the trawl as a commercially important moving gear, although many of the arguments that follow will be equally applicable to other fishing gears.

2 CONCEPTS

The fundamental concept is that of information transfer primarily by means of acoustic and radiant energy, shown simply in Fig. 1. Three main pathways are important:

1. Stimulus → reactor
2. Stimulus → observer
3. Reactor → observer

It is important to note that this picture has been oversimplified in that the fishing gear is shown as the stimulus but it is merely part of an environmental stimulus situation to which the fish is constantly reacting. For example, the distribution of light originating from the sun, around the fish at any one time, is part of its natural environment but when this light is reflected from an item of fishing gear it then becomes a novel stimulus. It is natural to assume that the closer the fish is to the gear, the greater is the relative significance of it. In the ideal situation (Fig. 1a) the observer or recording apparatus cannot be perceived by the fish. (No distinction is made in this paper between observation and recording, as in practice for any observation to be of value, some record of the information must be retained). Actual situations (Fig. 1b) often fall short of the ideal in that the fish may be aware of the observer who then forms part of the total environmental stimulus. Even greater departures from the ideal will occur in those cases where it is necessary to introduce an artificial energy source, although it is sometimes possible to restrict the output of energy to frequencies to which fish are insensitive, e.g. high frequency sound.

The physical properties of the medium affect the energy transmission and thus the transfer of information along the channels shown. Water turbidity affects the transmission of light to a much greater extent than the transmission of sound, therefore acoustic techniques are particularly suited to longer range operation and to use in turbid water. Abrupt changes in the nature of the medium such as thermoclines may, however, form barriers to the rectilinear propagation of sound by acting as nearly perfect reflectors.

3 THE STIMULUS - FISHING GEAR

A trawl is not a simple stimulus but a large and complex assemblage of optical and acoustic stimuli originating in different parts of it. The otter board and associated bridles and spreading wires are discussed as forming a good example of this complexity. An otter board is visible to the fish and to the observer at a distance dependent upon its spectral reflectance, the spectral luminance of the background against which it is seen, the contrast attenuation properties of the water and the prevailing light intensity. The wires are visible at probably rather smaller distances due to the visual acuity problem that they present. A visible cloud of disturbed sediment behind the board may reinforce the effectiveness of the bridles and spreading wires as herding devices.

When the senses possibly involved in the reaction of fish to fishing gear are under consideration vision is often unjustifiably ruled out. Experimental and field studies have given rather variable estimates of the critical thresholds of light intensity at which behaviour such as feeding and schooling ceases or commences. Similar arguments

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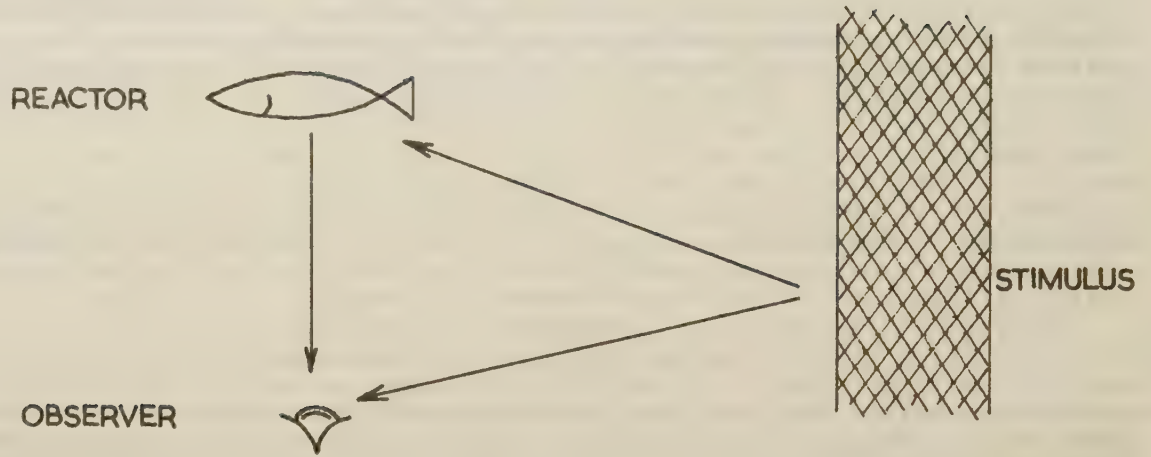
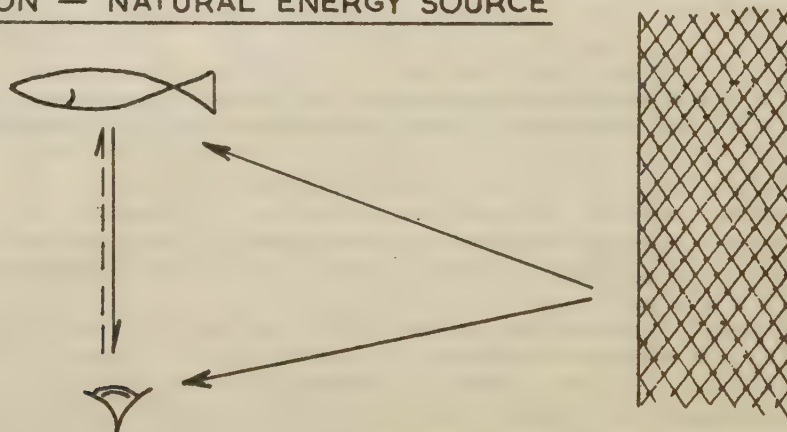
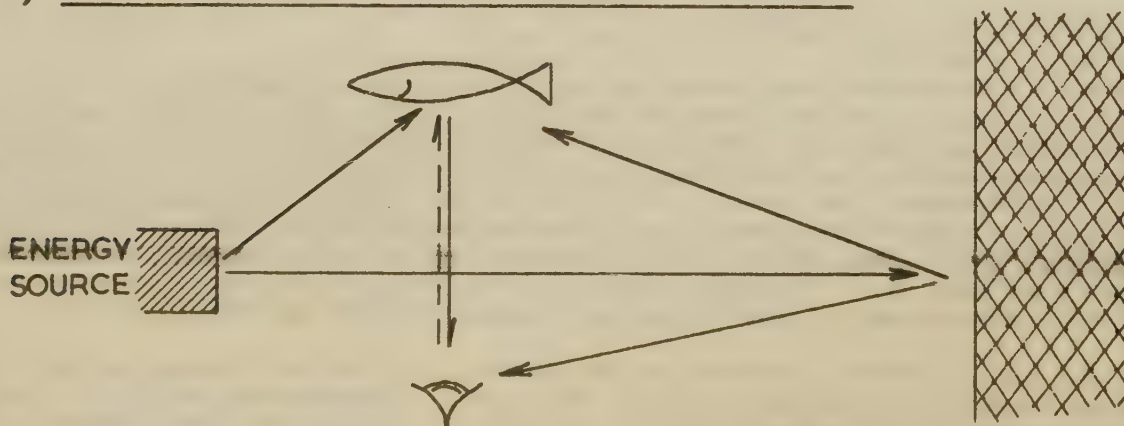
(a) IDEAL SITUATION(b) ACTUAL SITUATION — NATURAL ENERGY SOURCE(c) ACTUAL SITUATION — ARTIFICIAL ENERGY SOURCE

Fig. 1 Information transfer: three possible observation conditions

are suggested for the avoidance of gear. However, only small numbers of luminescent planktonic organisms such as dinoflagellates or ctenophores are necessary to make a moving object visible. These luminescent organisms tend to flash when they are disturbed by water movements, and in this way the turbulent water mass behind the boards and the turbulent trail behind each wire may be very conspicuous. In many waters the presence of luminescent plankton can be considered the rule rather than the exception. Two further points must be remembered, firstly that due to layering of plankton, there may be no evidence of luminescence at the surface, and, secondly, that if the ambient light intensity is low, the eyes of the fish will be highly adapted to perceive the low luminances involved in planktonic flashing.

Turning to acoustic stimuli (using the broadest sense of the word 'acoustic') there is a standing pressure wave or damming effect in front of an otter board which will vary in nature with its design and angle of attack. The trail of turbulence behind the board has already been mentioned in connection with visual stimuli, but it must be remembered that this trail will occur irrespective of the nature of the bottom and even in midwater. A board in contact with the bottom will generate a variety of sound frequencies as it moves over different bottom types. Hydrodynamic or water noise may be insignificant in comparison with bottom contact noise, but it is important in the pelagic case. The oblique movement through the water of the bridles in which large tensions are set up by the drag of the gear, will result in relatively low frequency vibrations which may be of considerable amplitude.

4 THE REACTOR - FISH

The gear technologist is concerned with the behaviour of fish in so far as behaviour equals movement, particularly in relation to certain parts of the gear. His simplest question is: 'What will fish do when they encounter this particular piece of fishing gear?'. The reaction of a single fish to fishing gear is the end result of a number of processes commencing with the reception of the information along the pathway 'stimulus-reactor' in Fig. 1, via one or more of the senses. The first consideration is that of the stimulus intensity which must be above a critical threshold for detection by the sense organ. Such detection thresholds for sounds of different frequency, light of different wavelength and visual acuity, for example, can be determined experimentally by conditioning techniques. However, conditioning shows the ultimate limits of sensitivity of a sensory system, but what in practice is more important is the response threshold, i.e. that intensity that results in the animal consistently performing a measurable response to the applied stimulus. This may be an order of magnitude higher than the detection threshold and is certainly much more variable. It is an unfortunate fact that the physiological condition of the fish may affect both thresholds in an entirely unpredictable way. Thus it is impossible to predict with any certainty the response of a single animal to a specified stimulus.

The second part of the problem is the reaction of the fish to the stimulus. This need not involve actual movement, but may merely be an arousal effect. The fundamental difference between radiant and acoustic energies could be significant here. Angular resolution is inversely proportional to wavelength, and as all acoustic frequencies to which a fish might be sensible have wavelengths several orders of magnitude larger than the wavelength of light, 'hearing' can never give as much directional information as vision, where angles between sources of a few minutes of arc can be resolved. It seems quite likely, therefore, that the acoustico-lateralis system of fish is used in part as a distant early warning of the approach of an object, raising the level of arousal. The eventual movement may thus be delayed until the object approaches within visual range. In low light intensity or in turbid water the object could approach sufficiently close that the intensity of the acoustic stimulus alone reaches a response threshold before visual perception occurs, but at this stage the sound sources are so much closer that the poorer resolution of them may not matter. The above suggestion is concerned with reactions to unfamiliar sounds, but if the sounds are familiar, as, for example, predator eating noise is to a prey, or prey swimming noise is to a predator, then there may be a more immediate response to the acoustic information without the waiting stage for visual contact to be established.

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(a) REACTION DISTANCE LARGE
IN COMPARISON WITH SIZE
OF NET.

(b) REACTION DISTANCE SMALL
IN COMPARISON WITH SIZE
OF NET.

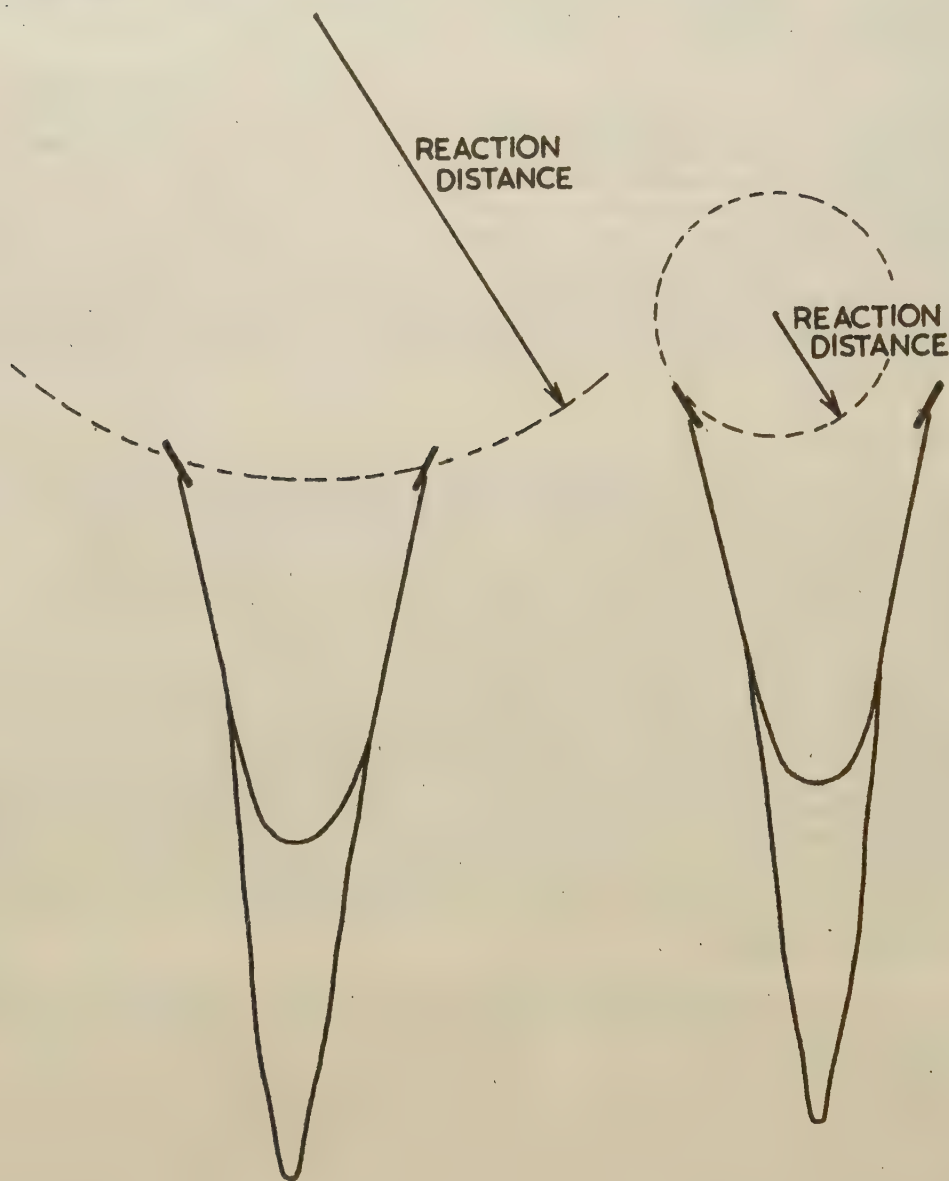


Fig. 2 Reactions distance compared with net sizes

This leads on to a consideration of the nature of the trawl as perceived by the fish. It is an entirely unnatural object in the fish's environment, but it must be assumed that the behavioural responses of fish to it are those that would be given to the stimuli generated by naturally occurring objects and situations, although the actual stimuli associated with the trawl may never have been experienced by the fish. It may help to take a human parallel and imagine a primitive people first seeing an aeroplane, an unknown object making an unknown sound. They certainly will be incapable of recognising it as a Boeing 707, but instead may consider it to be an overgrown insect, a giant bird or an unknown god. Their response may be motivated by fear, inquisitiveness, aggression or even hunger. It could result in their trying to make it land, to shoot it down or merely to worship it. All of these are behaviour patterns developed as natural responses to familiar stimuli, being shown in this case to an unnatural object. Similarly, because the trawl is such a complex assemblage of stimuli it is not possible to determine without experimentation, which of a variety of stimuli above the detection threshold actually trigger particular responses. It is even less possible to analyse the 'motivation' of fish in showing such behaviour as is seen to occur. It may not even be valid to analyse the situation in this way at all. It is quite likely that the response to stimulus 'X' in the presence of stimulus 'Y' at a certain value, is a response 'A', but that at some different value of 'Y', the response to the same stimulus 'X' is not 'A' but 'B' or 'C'. Perhaps the clue to understanding how the fish are actually responding to fishing gear lies in trying to understand what natural stimulus situation results in similar or identical behaviour, and then to determine if there are features common to both cases.

Fish do not usually allow strange objects to touch them, and therefore one can assume that at some stage the reaction to an approaching trawl will be to swim away from it. It is helpful to consider theoretically how variation in the size of the gear and the properties of the water might affect the behaviour of fish according to the principles suggested above. Acoustic and radiant energy both attenuate with distance according to measurable physical laws, thus the detection and reaction thresholds can be expressed as detection and reaction distances. Figure 2 shows two examples in which the reaction distances vary by a factor of five. (Although it is shown as a variation of the water transmission with constant sized gear, an exactly similar situation exists if one imagines gear of different sizes in water of constant transmission.) In the first case the fish begins to react when still a long way from the approaching net, but in the second it may be very close to the net before it begins to react. Considering vision only, it is apparent that in clear water or with relatively small nets the behavioural problem is one of guiding fish into the catching area (Fig. 2a), whereas with large nets or in turbid water the problem becomes one of preventing the escape of fish (Fig. 2b). When making a big net it may not be enough merely to scale up a small net and assume the occurrence of the same behaviour, which for the above reasons, is almost bound to be different.

5 OBSERVER/RECORDER

To gain a complete understanding of animal behaviour, the behavioural biologist is at some stage concerned with the activity of one animal, the performance of individual sensory systems and finally perhaps single sensory cells. It is virtually impossible to get down to this ultimate level in a field study but the behaviour of individual animals is vital. The animal, in this case a fish, must be correctly identified, observed for as long and as unobtrusively as possible, with continual monitoring of the environmental parameters that may affect its behaviour. The most important aspect of behaviour in fish capture by a moving gear such as the trawl is the movement of the fish relative to the stimuli which the gear is producing. For meaningful analysis, movement must be broken down into the direction, duration and speed of individuals of different sizes and different species. These parameters almost certainly vary with external factors such as light intensity and temperature, and internal factors such as breeding condition. The report of Mohr (1963) is an interesting example of the variation in behaviour of schools of pre-spawning, spawning and spent herring.

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No single observation/recording system satisfies all the requirements, but each has its own advantages and disadvantages. In general the image-forming optical techniques give more information and have the following advantages:

1. Accurate identification of species.
2. Orientation of individuals within the visual field and to each other easily determined. This is usually only useful if the visual field of the apparatus can be precisely defined.
3. Positional orientation of individuals in relation to the optic axis of the instrument is accurate, i.e. good angular resolution.

A similar catalogue of disadvantages can also be drawn up:

1. Poor range determination (improved by the use of stereo pairing).
2. Very limited range due to diffuse attenuation of light from source, and contrast attenuation between subject and observer.
3. Commonly low prevailing light intensity makes the use of artificial lights common. The use of intermittent flash and still cameras reduces the behavioural disturbance, but the information content of a still photograph is much less than a ciné or other continuous record.

Acoustic techniques for observation of behaviour are almost entirely of the echo-ranging type, which have as advantages almost exactly the reverse of the optical devices, i.e. the sonar devices are good at range determination but poor at angular resolution except for sector scanners and 'pencil' beam sounders. These are at present limited to one plane of view. Target identification is a continuing problem and orientation can only be deduced from movement. One major advantage of acoustic techniques, that some still dispute, is that the acoustic energies used are of frequencies largely outside the sensitivity range of the fish.

The various methods have been brought together in Table I which relates image-forming and non-image-forming techniques to the energies which they receive. The devices are arbitrarily classified as continuous or discontinuous on a 'behavioural time scale'. For example, the ciné-camera and the echo sounder produce a physically discontinuous record, but the repetition rate is sufficiently high that for behavioural purposes the record is continuous.

Given the choice, most biologists would prefer an optical image-forming system despite the limitations because they are used to behaviour being a subject studied visually. But it is also true to point out that much of the information contained in a visual image is not used in behavioural analyses. However, much attention is being devoted to methods of increasing the range at which image-forming devices can be used, especially in turbid water. Some of these techniques which are being developed for commercial and military search purposes could be of practical value in behaviour studies in the open sea. The problem of viewing through turbid water can be reduced to that of eliminating the back-scatter of light towards the receiver. A number of ways of doing this exist, including the use of plane polarising filters in natural light (Lythgoe and Hemmings), circular polarising filters with artificial light (Gilbert and Pernicka), laser scanning (Angelbeck) and pulsed laser with range-gated receiver (Martin, Heckman). A new and promising technique is the use of acoustic imaging (Muehlner) in which an incoherent sound source is used to insonify (the acoustic equivalent of illuminate) objects whose reflected sound is focussed by an acoustic lens on a transducer resulting in a video image. Although subject to the long wavelength diffraction problems mentioned above, this instrument is potentially valuable.

TABLE I - The various systems of observation/recording
and their sources and forms of energy

Energy	Energy Source	Continuity	Observer/Recorder		Continuity
			Image-forming	Non-image-forming	
Radiant	The Sun	C	1. Eye, TV camera, Ciné camera	C Photometric apparatus	D/C
			2. Still camera	D	
Acoustic	Noise from 1. Stimulus 2. Reactor	C	Hydrophones		C
		C			
Radiant	Incandescent lamps etc	C	1. Eye, TV, ciné camera	C	
	Flash lamps	D	2. Still camera	D	
	Pulsed laser	D	Still camera	D	
Acoustic	High frequency "ping" source	C	Range-gated receiver	D	C
	High frequency sound source (= insonifier)	C	Acoustic camera	C	
			Echosounders sonars Sector scanners		

C = continuous D = discontinuous

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6 CONCLUSIONS

The most significant behaviour patterns in connection with fish capture are the movements of fish in the vicinity of fishing gear. Accurate prediction of these movements is obviously the desired end of applied behaviour studies. This can only be attempted when there is a more complete understanding of fish behaviour in relation to the sum total of the internal and external stimuli affecting behaviour, of which those from the gear are part.

The first stage is to concentrate on the three information pathways discussed above between stimulus, reactor and observer. In practice this must mean that for any experimental fishing program to take account of fish behaviour, there must be at least as many information channels available for the behavioural biologist as there are instrument channels for the gear technologist. The biologically significant parameters that must be monitored by those channels cover factors that can be classified as 'direct' or 'indirect'. The indirect factors include absolute light intensity, the beam attenuation coefficient of the water, high and low frequency sound levels at different points and water flow and turbulence around the gear. The direct measurements must be made on individual fish and they primarily comprise speed, direction and duration of movement, as it is these that directly affect the success of capture. The line of argument followed in this paper can perhaps best be summarised by stating that behaviour study is a matter of observing and recording the activity of individual fish, and it cannot be carried out merely by counting and measuring what comes up in the cod-end of a trawl.

7 REFERENCES

- Angelbeck, A.W., Application of a laser scanning and imaging system to underwater viewing. In Underwater photo-optics. Seminar Proceedings of the Society of Photo-optical Instrumentation Engineers, Santa Barbara, Oct.10-11, 1966. Santa Barbara, Society of Photo-optical Instrumentation Engineers
- Gilbert, G.D. and J.C. Pernicka, Improvement of underwater visibility by reduction of backscatter with a circular polarisation technique. In Underwater photo-optics. Seminar Proceedings of the Society of Photo-optical Instrumentation Engineers, Santa Barbara, Oct.10-11, 1966. Santa Barbara, Society of Photo-optical Instrumentation Engineers
- Heckman, P.J., Underwater range-gated photography. In Underwater photo-optics. Seminar Proceedings of the Society of Photo-optical Instrumentation Engineers, Santa Barbara, Oct.10-11, 1966. Santa Barbara, Society of Photo-optical Instrumentation Engineers
- Lythgoe, J.N. and C.C. Hemmings, Polarised light and underwater vision. Nature, Lond., 1967 213(5079):893-4
- Mehr, H., Reaction of herring to fishing gear studied by echo sounding. In Modern fishing gear of the world, Fishing News International and Fishing News (Eds), London, Fishing News (Books) Ltd., vol.2:253-7
- Muehlner, J.W., Acoustic camera: turbid water does not affect image. Ocean Industry, 1967 2(4):29-38

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OBSERVATIONS ON THE BEHAVIOUR OF FISH
MADE WITH THE BIFOCAL SECTOR SCANNER 1/

by

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Abstract

Sea trials have been carried out with the Admiralty Research Laboratory's Bifocal sector-scanning sonar. Observations have been made on fish shoals and on the behaviour of fish in and ahead of an Engel trawl. Fish in the mouth of the trawl fell back into the square and subsequently swam up the wings to escape from the net. Fish were seen to keep station when close to the bridles and when 40 m ahead of the trawl. A film of the Bifocal display will be shown.

LE COMPORTEMENT DU POISSON OBSERVE AU MOYEN
DU SONAR "BIFOCAL" A BALAYAGE DE SECTEUR 1/

Résumé

Le sonar "Bifocal" à balayage de secteur du Laboratoire de recherche de l'Amirauté a été essayé en mer. Les observations ont porté sur des bancs ainsi que sur le comportement des poissons à l'intérieur d'un chalut Engel et en avant de celui-ci. Les poissons se trouvant dans la gueule tombent dans le grand dos et remontent ensuite le long des ailes pour s'échapper du filet. On a constaté que les poissons se trouvant à proximité des bras soit à 40 m devant l'engin se maintenaient à une distance constante du chalut. Il sera projeté un film montrant l'image fournie par le dispositif "Bifocal".

1/ Accompanied by a 16-mm film
Avec projection d'un film de 16 mm

OBSERVACIONES SOBRE EL COMPORTAMIENTO DE LOS PECES REALIZADAS
CON EL SONAR BIFOCAL DE EXPLORACION POR SECTORES 1/

Extracto

Se han realizado ensayos en el mar con el sonar bifocal de exploración por sectores del Laboratorio de Investigaciones del Almirantazgo. Se llevaron a cabo observaciones de bancos de peces y el comportamiento de éstos en el interior de una red de arrastre Engel y delante de ella. Los peces que se hallaban en la boca de las redes retrocedieron a la visera y después nadaron hasta las alas para escapar de la red. Se vió a los peces alinearse cuando se encontraban cerca de las mallas y cuando estaban a unos 40 m por delante de la red. Se proyectará una película sobre lo realizado con este sistema.

1/ Junto con una película de 16 mm

1 INTRODUCTION

Voglis and Cook (1966) have described a form of sector-scanning sonar developed at the Admiralty Research Laboratory, Teddington. This equipment, known as Bifocal, has been used in sea trials in conjunction with the Fisheries Laboratory, Lowestoft. Cushing and Harden Jones (1966) have described those results of the trials which were of particular relevance to fisheries work. Some of the results obtained with the Bifocal equipment were filmed and a short film will be shown at the Bergen meeting. This paper only contains such details of the equipment thought necessary to interpret the film. Finally, there is a brief summary of the progress being made with the installation of the equipment on the Ministry of Agriculture, Fisheries and Food's research vessel, CLIONE.

2 ACOUSTIC PARAMETERS AND DISPLAY ARRANGEMENTS

The equipment was used in a wide angle search made with a 30° scanned sector in the horizontal plane. The relevant parameters are summarized in Table I. The transducer body containing the transmitter and receiver were enclosed in an acoustically transparent dome, centred about the keel of the Admiralty ship. The transducer assembly was mechanically stabilized against pitch, roll and yaw and the transducer could be trained in azimuth (in the horizontal plane) and tilted (in the vertical plane) by manual control.

TABLE I - Acoustic parameters and characteristics of the Bifocal equipment used in the Bristol Channel trials

Operating frequency	300 kHz
Pulse repetition rate	4 per sec
Transmitter characteristics	
Array form	curved
Horizontal beam width	30°
Vertical beam width	5°
Nominal range resolution	8 cm
Receiver characteristics	
Array form	Linear
Number of elements	75
Horizontal beam width	0.33°
Vertical beam width	10°
Horizontal scanning of receiver beam	
Scanning rate, scans/sec	10000
Scanning sector	30°
Number of independent channels	75

The display consisted of a twin panel B scan on a rectangular CRT (35 cm diagonal) with a phosphor screen, whose effective storage time was 1 to 2 sec. The display on each panel corresponded to 91 m in range and 30° in azimuth. As the right-hand panel represented the range extension of the left-hand panel, the two covered a sector extending in range to 183 m, 1 m (91 to 92 m) being lost between the panels. This 1 m was not lost on the expanded display. There were two displays, one used by the operator, the other for photographic recording. The photographic display included another CRT on which any 46 m range gate of the 30° sector could be expanded. Photographs (16 mm) were taken by single exposures synchronized with the outgoing pulse and each frame included data relating to frame number, time, date, and bearing of the transducer relative to the ship's head. In interpreting the film it is helpful to remember that the width of the 30° scanned sector is approximately half the range of detection.

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3 THE FILM

The trials took place in the Bristol Channel area and the depth of water ranged from 33 to 46 m. It is probable that many of the shoals in the area were pilchards. There are three main sequences in the film and these notes are only intended to draw attention to the main points of interest.

3.1 Fish shoals observed from a ship steaming at 5 knots

When searching for fish the transducer was trained from port to starboard. Targets closed rapidly in range, and small shoals of a variety of shapes and sizes were detected out to maximum range. In some instances individual fish appeared to be resolved. One sequence shows, for a few frames only, sand ridges on the bottom.

3.2 Fish shoals observed from an anchored ship

The films are poor as the brilliance on the monitor display was set incorrectly. Small shoals, a few metres in diameter, were tracked to maximum range. The behaviour of two ribbon shoals was followed in detail; note "outriders" or "scouts" at the leading edges. The two ribbons joined up, one turning towards the other when they were 22 m apart.

3.3 Behaviour of fish in relation to a midwater Engel trawl

The Admiralty ship, carrying the Bifocal equipment, followed CLIONE which was towing an Engel trawl. Warps, doors, bridles, headrope, footrope, floats and the outline of the main frame of the net are clearly shown on the display. Fish were seen to fall back from the mouth of the net on to the right half of the square. Here the group divided, both halves moving forward, one along the left wing, the other along the right wing. All these fish escaped from the net, which was empty when hauled. Fish were seen to swim along with the bridles, and a single fish, or a small group of fish, kept station with the gear 40 m ahead of the trawl and 22 m away from the nearest door.

4 FUTURE WORK

The results of these trials show the potential use of the equipment for gear and behaviour work. Progress is being made in installing this sonar on R.V. CLIONE. The maximum range has been increased from 180 m to 364 m and certain changes made in the display arrangements. The transducer will be stabilized against roll, pitch and yaw, and a hydraulic-actuated system has been designed for installation in CLIONE.

Certain modifications have been made to the ship; a tube has been installed to allow the transducer and stabilization package to be lowered below the hull and provision made to accommodate a dome which can be removed and replaced by a cover plate. The equipment will be operational early in 1968 and an extensive program of work has been planned. We expect that our work will help to determine in what direction sector-scanning sonar may be most profitably developed for fisheries work (range versus resolution), as well as providing some direct answers to fish and gear problems (avoidance and escape).

5 REFERENCES

- Cushing, D.H. and F.R. Harden Jones, Sea trials with modulation sector scanning sonar.
1967 J.Cons.perm.int.Explor.Mer. 30:324-45
- Voglis, G.M. and J.C. Cook, Underwater applications of an advanced acoustic scanning
1966 equipment. Ultrasonics, 4:1-9

ON THE ESCAPEMENT OF FISH THROUGH THE UPPER PART OF A HERRING TRAWL

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Abstract

A method for evaluating escapement of fish through the upper part of a herring trawl is described and the results of field test are discussed. Escapement through the wide-meshed fore-part of the trawl was accomplished by all species caught, particularly herring. Mesh size, colour of netting, sizes of fish, relative swimming ability and times of fishing are considered.

OBSERVATIONS SUR LA FUITE DES POISSONS
PAR LA PARTIE SUPERIEURE D'UN CHALUT A HARENGS

Résumé

L'auteur présente une méthode permettant d'évaluer le nombre de poissons qui s'échappent par la partie supérieure d'un chalut à harengs ainsi que les résultats d'essais sur le terrain. Toutes les espèces capturées et notamment le hareng, parviennent à s'échapper par la partie antérieure, à mailles larges, du chalut. L'auteur passe en revue le maillage, la couleur du filet, la taille des poissons, leur capacité relative de nage, et le moment de la pêche.

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LA HUIDA DE LOS PECES A TRAVES DE LA PARTE SUPERIOR
DE UNA RED DE ARRASTRE PARA ARENQUE

Extracto

Se describe un método para evaluar la huida de los peces por la parte superior de una red de arrastre para arenque, y se examinan los resultados de la prueba práctica en el mar. Individuos de casi todas las especies capturadas, especialmente los arenques, escapaban por las anchas mallas de la parte anterior de la red. Se estudian el tamaño de la malla, el color de los paños de la red, las tallas de los peces, la capacidad natatoria relativa y las horas en que se efectúa la pesca.

1 INTRODUCTION

Mesh sizes in trawlnets usually diminish from the front part of the net to the cod-end. In the codend, where the smallest meshes are found, the mesh size is adapted to the size of the fish to be caught.

This construction - large mesh sizes in the foremost part of the net - enables the water to flow swiftly through the net, thus reducing the pressure waves in front of the net and promoting the filtering capacity, all of which increases the fishing capabilities of the gear.

The advantages gained through the large mesh sizes in the front section of the net could, however, be lost if fish escaped in great numbers. These meshes are generally large enough to allow most of the fish entering the net to escape. Escapement will be limited or even absent if the fish tend to avoid the walls of the net and thus be guided towards the codend. Observations in some fisheries with fixed nets, where certain fish are guided with the help of weirs with very large mesh sizes or by spaced poles, make such a behaviour plausible.

The objective of this study was to establish whether and to what extent escapement occurs through the wide meshes in the front section of a trawl. Further, to investigate the effect of mesh size and to some extent the colour of the net on this escapement. The ultimate aim of the study was to gather information to arrive at an optimal mesh size and net colour for the front section of herring trawls where rapid filtration must be combined with low escapement.

2 METHODS

Experiments were carried out with a herring trawl in the North Sea. Details of the gear used are shown in Fig. 1.

The trawl was adapted to the power of the R.V. WILLEM BEUKELSZ (200 B.H.P.), which is considerable less than the power of commercial vessels trawling for herring. The speed of the vessel during fishing was about 3.5 kn. The herring trawl used in the experiments had a total headline length of 45 ft, whereas commercial vessels usually have trawls of 63 to 72 ft headline length.

In two parts of the gear, i.e., in the foremost part of the upper square (position 1) and in the upper part of the net, where the mesh size was about 70 mm and thus well before the funnel (position 2), holes were cut so that exchangeable pieces of netting could be attached (Fig. 1). The holes were lined with thin nylon rope, to which the cut meshes were attached. Test-panels with netting of variable mesh sizes and/or colour were edged with nylon rope of the same thickness. A test-panel could be placed in the net by braiding the nylon ropes of net and test-panel together. The test-panels were 1.8 x 2 m (3.6 m²) and the number of meshes varied with the mesh size.

To retain escaping fish the test panels were provided with a small mesh cover with a long codend. The mesh size of the cover, which was made of rather thinner twine than the net was 35 to 40 mm and the codend had a length of about 3 m (Fig. 2). Test-panels had mesh sizes of 80, 100, 120, 150, and 200 mm.

The herring trawls used were made from polyethylene fibre (Nymplex), construction 3 x 3, coloured green. The same material was used in the test panels. The covers, however, were made of green polyethylene, construction 3 x 2.

The technique used here to estimate escapement through the upper part of a trawl is open to criticism. Firstly, it is not quite certain whether this construction fitted the lines of the net fluently. It is possible that, notwithstanding the netmakers' expert advice, the test-panels were either too small or too large compared with the original piece of netting which had been removed. The fact that after a series of successful hauls the net started to tear in the upper square, suggests an inadequacy of

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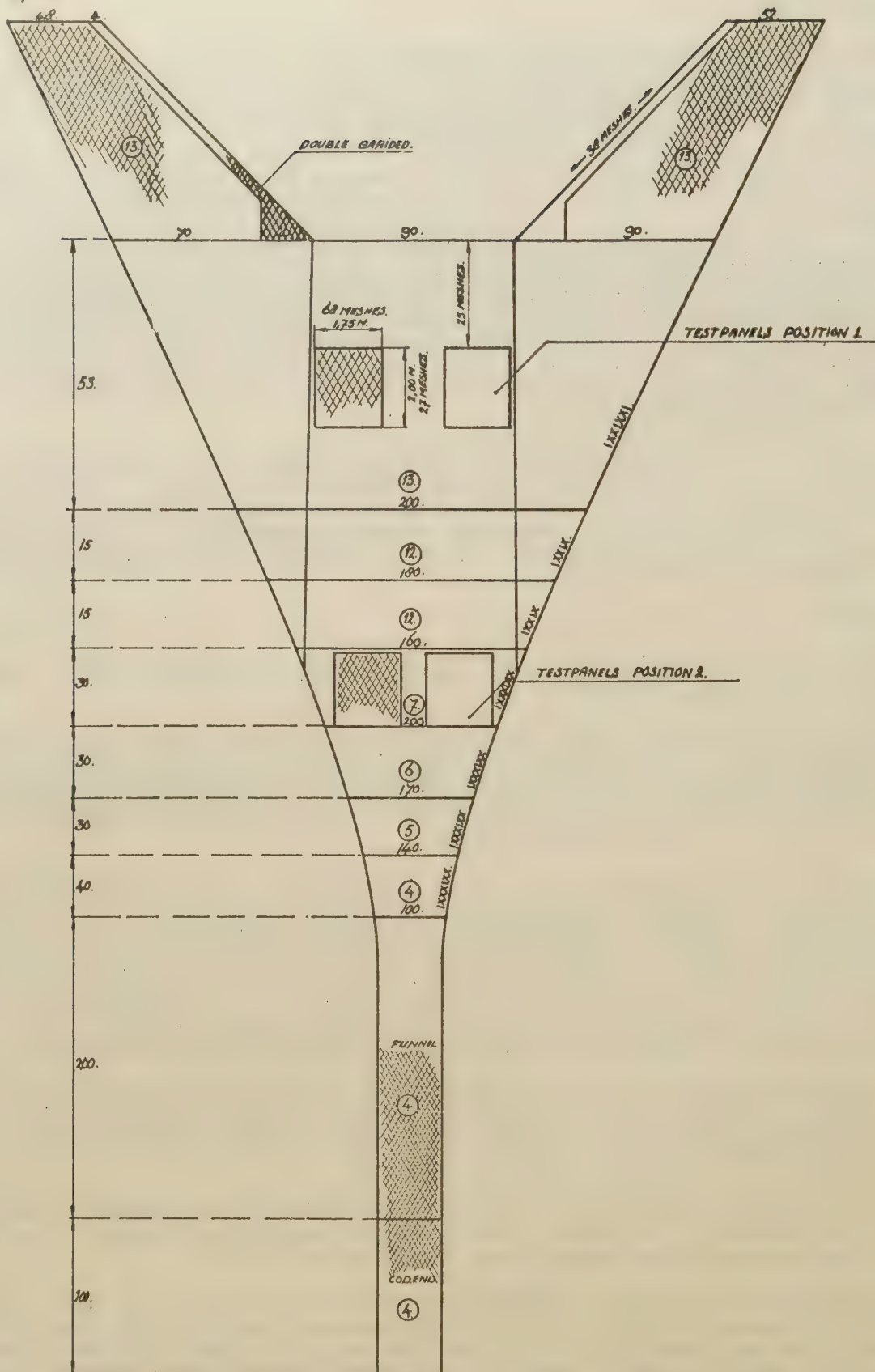


Fig. 1 Position of test-panels in the experimental herring trawl.

the construction, which certainly may have affected escapement. Another objection to the method used is that fish escaping through the test-panels into the cover may have returned to the net, thus giving an underestimate of escapement. A third objection could be that part of the fish found in the covers escaped during the hauling operation, when the speed of the net through the water was reduced and some fish could have swam forward in the net. This objection will especially apply to the escapement through test-panels in position 2, close to the codend.

In the experiments three separate series can be distinguished:

- (a) The first series was carried out in the western North Sea (Farn Deep area), in July 1958. Fishing took place at depths between 55 to 92 m. A total of 13 hauls were made, with test-panels of 80 and 120 mm mesh size, coloured green, both in position 1 and 2.
- (b) In the same period and area 9 hauls were made with test-panels with a mesh size of 100 mm, coloured green and yellow, in position 2 only. The test-panels in position 1 had been removed, because of tearing of the net in the upper square (see above). These hauls were made with a new net after tearing the one used in series (a) on a rough bottom.
- (c) A third series of 10 hauls was made in the vicinity of the Dogger Bank in September-October 1958. Again, test-panels were only placed in position 2. The test-panels had meshes of 150 and 200 mm, and were coloured green.

3 RESULTS AND CONCLUSIONS

In presenting the results of the experiments some tentative conclusions will be drawn. The results will be given in a summary form, showing rather the sum results of a number of hauls than the results of single hauls. It is realised, that due to the limited power of the research vessel, the catches were rather too small to draw firm conclusions. The preliminary conclusions are:

3.1 Species escapement through the test-panels

All species of fish caught were found to escape through the test-panels, as is shown in Table I. The data in Table I do not take into account the position, the mesh size or the colour of the test-panel, nor the series.

TABLE I - Total escapement of fish through test panels (3.6 m^2) in the upper part of a herring trawl

Species	Catch in codend (numbers)	Escapement through test-panels (numbers)	(% of total catch)
Herring	15,000	283	1.89
Whiting	4,000	15	0.37
Cod	1,300	0.5	0.04
Haddock	800	1.25	0.16
Norway pout	58,000	310	0.53
Dab	240	0.5	0.21
Long dab	1,030	2.75	0.28

Escapement appears to be different for the species caught, herring showing the greatest escapement, cod the least. Escapement may seem to take place only on a small scale, but it should be realised that the total area of the upper part of the trawl in front of the codend is about 40 times as large as a test-panel. Without giving very precise information, the data suggest that total escapement of some species through the upper part of the trawl may have been considerable.

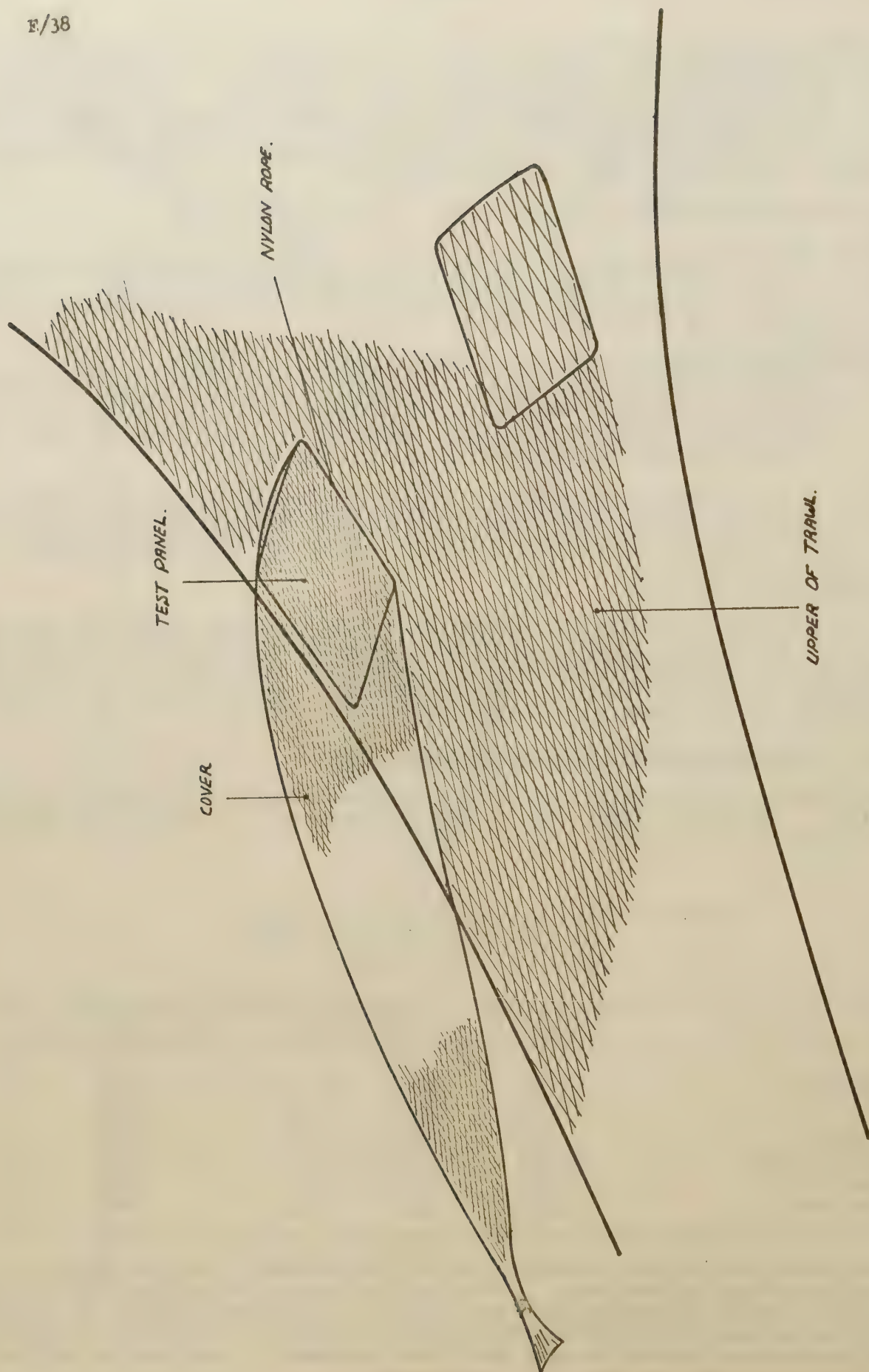


Fig. 2 Details of the test-panel attachment in the upper part of the trawl

3.2 Relative escapement according to position of test-panels

Most species showed greater escapement through the test-panels just in front of the funnel (position 2) than through those in the square of the net (position 1), with the exception of Norway pout, which was found to escape in far larger numbers through the test-panels in the square (Table II). The above observation is based on data derived from experimental series (a). The aberrant escapement of the Norway pout is not easily explained. Their vertical distribution may be different from the other species, placing them in closer proximity to the headline. Alternatively, the limited swimming power of these little fishes, may make it impossible for them to avoid the walls of the net. In addition, we can expect that most of the water entering the net is leaving it again through the wide meshes in the square. The other fish could possibly avoid the walls of the net, escaping only just prior to entering the codend or possibly during the hauling operation.

TABLE II - Relative escapement in number of fish through test-panels in the forward (position 1) and rear (position 2) part of the net

Species	Catch in codend	Escapement through test-panels	
		Position 1	Position 2
Herring	4,100	25	86
Whiting	920	1.5	4.5
Cod	800	-	1
Haddock	500	0.5	1
Norway pout	44,000	416	76
Dab	110	-	-
Long dab	620	0.5	1

3.3 The effect of mesh size on escapement through test-panels

There was a clear-cut effect of mesh size on escapement. Larger meshes allow for more escapement, as shown in Table III. In the series (a) and (c), where two mesh sizes were tested simultaneously, the effect of mesh size is clear for all species where sufficient numbers were taken.

However, when the data of the three series are compared for the same position of the test-panel, the evidence for a larger escapement by wider meshes is less firm. (Table III, percentage escapement for different mesh sizes in position 2.) This may be due to differences between the series: in series (a) the net used was different from the one in series (b) and (c), whereas in series (c) the fishing ground and the condition of the herring (maturity stage) differed from the situation in series (a) and (b).

The increase in escapement with larger mesh sizes could be related to some sort of "mesh-selection", i.e. that smaller fish are escaping more than larger ones. For two species, herring and whiting, length data were available in large enough numbers to investigate this point. In Table IV the escapement of herring and whiting of different size-groups as compared with the codend catch (percentages) is shown for a variety of mesh sizes. The data show that smaller herring escaped more than larger ones through 80 and 100 mm mesh panels. A similar size related escapement was found with whiting in 120 mm mesh panels. A mesh size to fish length relationship, however, was not indicated in the other mesh size groupings.

Although there are some indications of a mesh-selection, it must be noted that this selection could as well reflect the inability of a fish to escape through a given mesh (=codend selection) or the greater ability of larger fish to stay away from the walls of

TABLE III - Escapement of fish in numbers (followed by percentage of total catch in parenthesis) through test-panels with different mesh sizes

Species	Catch in codend	Escapement through test-panels			
		Position 1		Position 2	
Series (a)		mesh: 80 mm	120 mm	mesh: 80 mm	120 mm
Herring	4,100	5(0.1)	44(1.1)	37(0.9)	136(3.3)
Whiting	920	- (0)	3(0.3)	- (0)	9(1.0)
Norway pout	44,000	257(1.3)	576(1.3)	65(0.2)	88(0.2)
Series (b)				mesh: 100 mm	
Herring	2,000				64(3.2)
Whiting	3,100				19(0.6)
Norway pout	14,000				62(0.4)
Series (c)				mesh: 150 mm	200 mm
Herring	9,000			151(1.7)	207(2.3)

TABLE IV - Escapement of herring and whiting of different length groups through test-panels of different mesh sizes, expressed as a percentage of the numbers of corresponding size groups in the codend catch

Mesh size	16-17 cm	18-19 cm	20-21 cm	22-23 cm	24-25 cm	26-27 cm	28-29 cm	30-31 cm
Herring								
80 mm	0%	1.0%	1.7%	0.8%	0.9%	0.4%	0.5%	0%
100 mm	0	7.0	7.9	4.6	0.8	3.7	2.7	1.8
120 mm	0	6.3	4.4	4.0	3.0	3.7	5.4	
150 mm	0	0.2	0.9	2.4	2.1	0.8	0.9	2.1
200 mm	0	0.5	1.5	2.6	3.4	1.3	1.3	2.1

Mesh size	15-20 cm	21-25 cm	26-30 cm	31-35 cm	36-40 cm	Over 40 cm
Whiting						
80 mm	0%	0%	0%	0%	0%	0%
100 mm	0.8	0.2	0.7	0.5	1.6	0
120 mm	13.0	2.8	1.7	0	0	0

the net, i.e. resist the water flow through the wider meshes in the fore-net. A codend type selection is highly unlikely for Norway pout and herring, as both species are able to escape even through an 80 mm mesh. Herring up to 32 cm long, with a selection factor of 4 could, for instance, escape through an 80 mm mesh. Whiting, with a selection factor of 3.5, could escape up to a length of approximately 28 cm through a 80 mm mesh, 35 cm through a 100 mm mesh and 42 cm through a 120 mm mesh. The figures in Table IV illustrate that a codend type mesh-selection is probably not very important, except possibly in such large species as cod or haddock.

It seems more likely that the swimming ability of the fish, enabling it to keep away from the walls of the net, is more important. With smaller mesh sizes the waterflow through a test-panel would be reduced and correspondingly the swimming ability needed to avoid the panel would be less. This type of mesh-selection seems to provide a better explanation for lower escapement of larger fish through the test-panels.

3.4 The effect of colour on escapement through test panels

Escapement through net material of a different colour (green and yellow) was different for herring and whiting, but not for Norway pout. This is shown in Table V, which gives the results of series (b), where green and yellow 100 mm mesh test-panels were used in position 2. The most likely explanation for the difference in escapement of herring and whiting in relation to the colour of the twine is that the fish could see the yellow panel far better than the green panel and thus avoid the former and not the latter. Norway pout, on the other hand, might have been unable to see the difference in colour or brightness, or more likely, might not have been able to keep away from either of the two test-panels.

TABLE V - Escapement in numbers of herring, whiting and Norway pout through green and yellow coloured test-panels (position 2) with a mesh size of 100 mm

	Total catch in codend (numbers)	Escapement through test-panels	
		Green twine	Yellow twine
Herring	2,000	64	33
Whiting	3,100	20	5
Norway pout	14,000	62	65

According to fishermen herring trawls made of untanned, light coloured materials (manilla, hemp or nylon) are more efficient than tanned, dark brown coloured nets. In the light of our experience with escapement through green and yellow test-panels one wonders whether such differences in fishing efficiency could be due to differences in escapement through the wide meshes of the fore-part of the trawl.

3.5 Escapement of herring during day and night hauls

The escapement of herring was generally higher during night hauls than during day hauls (Table VI). The difference in day and night escapement was only considered for herring, as catches of other species were small.

A possible, and to my view likely explanation for the differences in escapement is that during darkness the herring cannot see the walls of the net and are therefore unable or less able to avoid them. In herring trawling it is a well-known fact that night catches are usually much smaller than day catches. This is partly caused by the vertical migration pattern of the herring, which leave the bottom zone during night hours and are not available to trawls. Another explanation for the relatively small night catches could be escapement through the wide meshes of the trawl during the night, because the fish were not able to see and avoid the netting.

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TABLE VI - Escapement of herring through the test-panels
as a percentage of the catch in the codend
during day and night hauls

	Escapement through test-panels	
	Day hauls	Night hauls
Series (a)	4.9%	8.2%
Series (b)	4.5%	24.0%
Series (c)	2.1%	19.4%

4 SUMMARY

Summing up the results of this attempt to estimate escapement through the wide-meshed fore-part of a trawl, we can say that escapement occurred in all species caught and might, for some species at least, be of rather great importance. This could be especially true for herring, which were found to escape in relatively large numbers even through the square of the net. Of practical importance is the fact that escapement seems to depend on mesh size, with more fish escaping through larger meshes. Finally there are indications, that fish tend to keep clear of the walls of the gear as was deduced from the higher escapement during night hauls, the difference in escapement with materials of different colour or brightness and, to some extent, from the fact that smaller fish tend to escape more than larger ones.

This preliminary study has shown that in net designing not only the hydrodynamic advantages of large meshes in the fore-net have to be considered, but escapement of fish through those wide meshes as well. There are indications that escapement could be reduced through increasing the visibility of the net material by using bright colours or material with a high light reflectivity. One could even consider the use of luminous material.

It is true that thought has been given to the problems outlined above in developing existing nets. These nets are certainly built on a compromise between the two conflicting requirements, i.e. large meshes for a high degree of filtration and small meshes to prevent escapement. However, whether important improvements could be made on this compromise is still a question and will be subject of further studies.

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PHILIPPINE PURSE SEINING WITH LIGHT ATTRACTION

by

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Abstract

A technique using light attraction as an aide to purse seining is presented. Experiments were conducted on the reactions of certain prevalent Philippine fishes (scoad, sardine, mackerel, matangbaka, tuna and bonito) to electric lights. Fish gathered deep under the lights but did not approach the surface until the light intensity was gradually reduced. These observations were used to develop the fishing technique. Vessels, gear and details of the operation are discussed.

PECHE A LA SENNE TOURNANTE A LA LUMIERE
AUX PHILIPPINES

Résumé

L'auteur décrit une technique de pêche dans laquelle la senne tournante est complétée par l'emploi de lumière. Des essais ont été faits pour juger des réactions de certain poissons communs aux Philippines (chinchard, sardine, maquereau, "matangbaka", thon et bonite) à la lumière électrique. Les poissons se sont rassemblés en profondeur sous les lampes, mais ne se sont approchés de la surface que lorsque l'intensité lumineuse a été graduellement réduite. La technique de pêche a été mise au point en se fondant sur ces observations. L'auteur passe en revue les bateaux et engins employés et les détails des opérations de pêche.

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PESCA CON REDES DE CERCO DE JARETA EN FILIPINAS,
CON EMPLEO DE LUZ PARA ATRAER A LOS PECES

Extracto

Se describe una técnica que emplea la atracción mediante luces como ayuda para la pesca con cerco de jareta. Se realizaron experimentos acerca de las reacciones de ciertos peces frecuentes en Filipinas (chicharros, sardinas, caballa, matangbaka, atún y bonito) a las luces eléctricas. Los peces se reunieron debajo de las luces a cierta profundidad pero no se aproximan a la superficie hasta que no se reduja gradualmente la intensidad de la luz. Se emplearon estas observaciones para desarrollar la técnica pesquera. Se examinan las embarcaciones, los artes y los detalles de la operación.

1 INTRODUCTION

During the period 1963-65 the Food and Agriculture Organization of the United Nations, under its Expanded Program of Technical Assistance, initiated a project directed toward the introduction of modern purse seining methods in the Philippine Islands. A number of survey cruises under this program revealed that fish schools were rarely found at the surface during daylight except for brief periods just before sunset and just after dawn. Consequently, it was decided that experiments with light attraction should be made to determine the feasibility of incorporating their use in a purse seining system. Light attraction with kerosene lanterns was being used successfully in the local "Basnig" liftnet fisheries.

The principal purse seining grounds are around Palawan and Zamboanga Islands. Fishing depths range from 9-146m with most operations in the 55-73m range.

2 FISH BEHAVIOR

Initial light attraction experiments were made with electrical lights. These provided greater brilliance and better control than could be achieved with the kerosene lights used locally. Only above-surface lights were used. Echo sounders were used to observe fish response patterns to light conditions and predators.

These tests showed that the fish reacted to the lights in a manner radically different from the assumed behavior. While the lights were effective in collecting the fish they did not approach nearly as close as had been assumed. They gathered deep under the lights and milled in a very large circle. It was found that by reducing the light gradually the fish would rise toward the surface or approach the lights, but only within a very large radius. The fish approached a small boat with few lights closer than a large boat with many lights. If the lights were dimmed too fast the fish often dispersed.

The principal species in these waters is the round scad (Decapterus sp) with some quantities of sardine (Sardinella sp), mackerel (Scomber sp), matangbaka (Caranx sp), tuna (Thunnus sp) and bonito (Sarda sp). In addition sharks, sailfish, dolphin and snakes were attracted either to the light or to other species milling under the light.

Round scad

The round scad were easily attracted by the light but remained close to the bottom. They were raised by dimming the lights.

Sardines

The sardines behaved in a manner similar to scad.

Matangbaka

Matangbaka, however, were very difficult to control. This species usually stayed in the shadow outside the circle of light up near the surface. Also, they did not school tightly but were scattered. When the light intensity was reduced they often dispersed even though the other species remained.

Mackerel

The mackerel formed small schools which moved in and out of the lighted area but spent most of their time in the light circle. They were also usually near the surface.

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Tuna and bonito

Tuna and bonito formed small dense schools under the light but usually remained only a short time. Dimming of the light usually dispersed them. During light attraction studies echo sounder observations showed that the various species do not intermingle. It was also observed that operation of the echo sounder appeared to drive off bonito and tuna. Consequently, when these species were attracted to the lights the echo sounder was not operated. 1/

3 FISHING GEAR AND VESSELS

The loose formation of the schools found in the light experiments suggested that relatively long purse seines should be used. Experiments showed that nylon seines 458-549m long and 73-92m deep (mesh size 20-25mm) were very effective when used with extension ropes. The two-boat method of purse seining was considered initially but rejected because a larger crew (minimum 20 men) is required and although setting is faster, manoeuvring into position is slower than with the one-boat method (8-9 men).

The fishery is conducted using a purse seiner, a light boat and carrier or follower boats. Each purse seiner may have from one to three follower boats.

Lighting is provided from both the purse seiner and the carrier vessels. The number of lights used depends on the length of the vessel. The average is about 40 (20 on each side of the vessel). The lights are usually 500W each and spaced about 1m down each side of the vessel. They are wired and controlled individually. The carrier vessels are equipped with the same lighting arrangement. The light boat carries one or two lights which are either electrical or kerosene. One of these lights is provided with a shade in the shape of a truncated cone. This is used for concentrating the light when it is necessary to raise the fish toward the surface.

4 FISHING OPERATIONS

The purse seiner usually starts operations in the afternoon. When fish are seen either on the echo sounder or at the surface they are followed until dark. Schools are usually so scattered during daylight that it is not worth setting. After dark the vessels (purse seiner and carriers) anchor and the fishing lights are turned on. After about one hour the fish can be observed on the echo sounder schooling near the bottom. When a sufficient quantity has gathered or if predators such as shark, sailfish or dolphin appear the setting operation is started.

The first step in the setting operation is for the seiner to turn out all deck and navigation lights. Only small covered lights over the winch remain on. Then the fishing lights are turned off one at a time over a period of 15 to 20 minutes, depending on the behavior of the fish. This can be a very critical operation because if the light is reduced too rapidly the fish may disperse. Also, it is necessary to alternate extinguishing of lights from side to side and from bow to stern. When only one light remains switched on aboard the seiner, the light boat with its lights on is anchored under it and the last fishing light aboard the seiner is turned off. The seiner then hauls its anchor and prepares to set. If the fish stay on the bottom or remain deep the light boat concentrates its light with the shade. The concentrated light has the effect of raising the fish toward the surface. The seiner then begins

1/ A similar observation on the effect of sonic signals on bonito has been made in Argentina. After pursing, if the sonar was directed into the net the bonito responded violently and were observed breaking water apparently attempting to escape. When the sonar was turned off the fish stopped their violent reactions.

the set and while it is setting the light boat hauls anchor and attempts to hold the fish near the centre of the seine. The seiner completes the set and only when the rings are on deck are the deck working lights turned on.

When the fishing operation has been completed the seiner moves to one of the follower boats which has been "lighting". The lights on the follower boat are extinguished as described above, the fish again "transferred" to the light boat and another set made. The use of carrier boats for "lighting" reduces the total time required (per seiner) for this phase of the operation.

The most productive fishing periods are during the dark of the moon. During this period the purse seiners make four to five sets per night. The catches vary from 1 to 100 tons per set, but average 5 to 10 tons.

In early fishing trials it was found that fish, particularly sardines and matangbaka, escaped through the hangings normally used in purse seines. This problem was solved by using twice as many hangings as normal along the floatline. Also, it was found that during the "drying up" operation a large amount of the catch escaped by jumping the floatline. Securing the floatline of the bunt to the booms (float booms) prevented this by bringing the bunt floatline 1 or 2m above the surface.

It was also found that occasionally during the hauling operation sharks attacked the netting from the outside resulting in severe damage. The sharks inside the seine, however remained calm and caused no damage.

* * * * *

FISH BEHAVIOUR IN RELATION TO DRIFT AND BAGNETS

by

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Abstract

The behaviour of fish in relation to underwater illumination, and the role of the sense organs in behaviour, is discussed. In particular, the effect of driftnet colour on catch was examined, there being a tendency for better catches where the brightness of the netting was high. The colour of bagnets was also important, greater catches of coastal fish being taken by brighter nets. Nocturnal fish were caught better by darker nets in the bagnet fishery.

COMPOTEMENT DU POISSON DEVANT LES FILETS DERIVANTS
ET LES FILETS A POCHE

Résumé

L'auteur examine la réponse du poisson à l'éclairement sous-marin ainsi que le rôle des organes sensoriels dans le comportement. Il étudie notamment l'influence de la couleur des filets dérivants sur les prises, celles-ci tendant à croître lorsque les filets sont de couleur claire. La couleur des filets à poche joue également un grand rôle, les engins de couleur claire capturant davantage de poissons côtiers. Par contre, pour la pêche des poissons nocturnes, les filets à poche de couleur sombre donnent de meilleurs résultats.

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EL COMPORTAMIENTO DE LOS PECES EN RELACION
CON LAS REDES DE DERIVA Y DE BOLSA

Extracto

Se examina el comportamiento de los peces en relación con la iluminación submarina, y la función que desempeñan los órganos sensoriales en el comportamiento. En especial, se analiza el efecto del color de las redes de deriva sobre las capturas, tendiendo a ser mejores las capturas cuanto mas brillante es la red. También es importante el color de las redes de bolsa, capturando las redes de más brillo mayores cantidades de peces costeros. En la pesquería de redes de bolsa se capturaron mejor los peces nocturnos con redes más oscuras.

1 INTRODUCTION

Quite different fishing gear may be used to catch the same species of fish under different fishing conditions and even, sometimes, on the same fishing ground. In the Sea of Japan sardines are caught mainly by driftnet because they disperse widely in low-density schools. Northwest of Kyushu they do not school at the surface by day, but at night purse seiners using light-attraction take sardine which swim slowly in dense schools within easy reach of the surface. Off the Pacific coast of Central Japan the sardine school near the surface by day are fished by two-boat purse seiners.

Light attraction is most effective where the transparency of the water is high and the temperature not too low. Light appears to be the most important stimulus, especially when moving. Man's range of visibility in the sea by day, though dependent on transparency, is 5 to 6 m. Judging from studies of the eye, fish may have almost the same visual capacity as man.

2 BEHAVIOUR AND ILLUMINATION

Observations were made of sardine behaviour in the southern part of the Sea of Japan. Before dawn when the illumination was low the schools were at a depth of 50 to 90 m. Immediately before sunrise when the light intensity was 10^{-1} to 10^{-2} lux at the depth of the fish the schools rose rapidly to the surface into an intensity of not more than 10^2 lux. Guided by echo sounders fishermen shoot their nets and make good catches at this time.

After sunrise, with further increase of light, the schools descended into deeper water remaining at light levels between 10^1 and 10^3 lux and forming dense schools at 40 to 70 m. Towards dusk as the illumination decreased the sardines again moved up. Fishing is again good at this time. Later the sardines descended again and from the echo sounding traces the schools appeared to disperse.

3 REACTION OF SCHOOLS TO DRIFTNETS

3.1 Visibility of the net

With drift nets the twine should be invisible to the fish, hence the wide use of monofilament nylon. With bagnets, however, the leader net has the function of guiding the fish and it should be as visible as possible.

3.2 Sound

Sounds produced by netting may also influence fish so that the twine of gill nets should be as thin as possible to reduce noise levels and turbulence. While a drifting net will tend to make rather little noise, in a bottom gillnet noise may be a serious factor; in a leader net vibration could be advantageous.

3.3 Diurnal changes in catches of driftnets

A survey was conducted in the sardine driftnet fishery at the end of May in the Sea of Japan (Niwa, 1952). The catch was minimal from 15.00 to 18.00, built up slightly from 18.00 to 19.00 and was maximal from 20.00 to 23.00. After a fall lasting an hour another peak occurred from 24.00 to 01.00 and thereafter the catch decreased hour by hour until another increase at dawn. These catches accord with the behaviour described in relation to illumination, i.e. an ascent towards evening when the fishing is good at depths of about 50 m. At night the fish disperse, but move up to the surface again at dawn.

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3.4 Colour of driftnets

In a fishing test of driftnet colour (Nomura, 1961) in the southern Sea of Japan a large net 75m x 20m was divided into 60 differently coloured panels each measuring 7.5 x 2m. The colours used were (in order of brightness measured at 50m) White (W), Yellow (Y), Green (G), Blue (B), Orange (O), Purple (P), Red (R), Gray (Cy), and Black (Bk), see Fig.1. This shows the order of the panels and the catch of sardines in the panels on each of 11 days. The catch in each panel on a particular day was compared horizontally with the adjacent panel to the right and the adjacent panel below. No attempt was made to use the numbers of fish but only whether the catch was higher or lower than in the adjacent panels. In this way each coloured panel could be allotted a score as shown in Fig. 2. Each part of this figure refers to a day, the column indicating relative brightness between adjacent panels and the rows indicating relative catch. If the reference panel was brighter than the panel to its right or below a value of one was scored in the positive column, if it was darker it was scored in the negative column. The vertical position of the score in the column was determined by relative catch. If the reference panel had a higher catch the score was placed in the positive row, if it had a lower catch, the score was placed in the negative row.

An example may illustrate this analysis more easily. Taking the upper left-hand panels in Fig. 1 it will be seen that the Green reference panel caught 8 fish on 15 January and the White panel to its right caught 17 fish on the same day. The Green panel is darker hence scoring in the negative column for that day, the Green panel caught less fish scoring also in the negative row, as shown below:

BRIGHTNESS CATCH			
	+	•	—
+			
•			
—			1

Each panel was similarly compared with its neighbour to the right and below for each day. It will be clear that a high score in the (—) (—) box indicates poorer catches in darker nets and a high score in the (+) (+) box better catches in brighter nets. Conversely high scores in the (+) (—) boxes indicate better catches in darker nets and poorer catches in the brighter nets. When the (+) (+) and (—) (—) boxes are summed and compared with the values in the (+) (—) boxes it is clear from Fig. 2 that the much higher scores in the (+) (+) and (—) (—) boxes indicate that the brighter the colour of netting the better the catch. This effect was not found in night fishing.

Another test by Koike (1958) in the salmon driftnet fishery compared the catch between cutch-brown and blue-green nets and between cutch-brown and grey nets. In both tests cutch-brown nets were the less efficient. In the fishing grounds of the North Pacific the water has a low transparency and is dark grey. It appears, therefore, that a net similar to the colour of the sea water is best.

← 7.5m →

G	W	R	G	B	O	P	Y	G _y	B _k	
8	5 15	17 8	24	10 105 11	4	9 31 10	1	10 11	1	10 11
20		11 2 1	15 6 2	18		14		12 2 5 5	18	6
O	Y	B _k	O	G	B	G _y	P	R	W	
21	2 15	4 10 1	45	5 78 10 34	1 73 14	3 36 0	32 23	3	25	4 40
20	2 2	30	24	31 1	8	18 1 1 1	10	2	19	2
P	O	B _k	Y	W	P	G _y	B	R	G	
26	2 1 19	19 32	29	78	34	24 1	31 1 1	1 36 1	12 3 33	24 10 65
6	8	27	9	25	3 13	1	2	23	23 15 5 8	2 4
G _y	B	Y	W	O	P	R	G	B _k	G	
9	9	4	28	55	10	20	1	33	27 21	6 18
4	22 1 1	7	3		4	9	13 16	1 21	19 20	
W	W	G	B _k	R	B	P	G _y	P	Y	
1	12	5	12	23	9	12	11	9	1	5
1	1	4					3	20	1 4	
R	G	R	Y	P	W	B	O	B _k	G _y	
1	28	5	1 9	10	1	2	1	4	1	9

Fig. 1 Number of fish caught by different coloured panels of a driftnet by day

HORIZONTAL ANALYSIS

8 JAN

	+	.	-	
+	1	0	1	2
.	0	0	0	0
-	0	0	2	2
	1	0	3	

(1+2)-(1+0)>0

11 JAN

	+	.	-	
+	6	0	2	8
.	0	0	0	0
-	0	0	5	5
	6	0	7	

(6+5)-(0+2)>0

13 JAN

	+	.	-	
+	2	0	0	2
.	0	0	0	0
-	0	0	2	2
	2	0	2	

(2+2)-(0+0)>0

15 JAN

	+	.	-	
+	7	0	6	13
.	0	0	0	0
-	4	0	6	10
	11	0	12	

(7+6)-(4+6)>0

25 JAN

	+	.	-	
+	11	0	9	20
.	1	1	0	2
-	7	0	11	18
	19	1	20	

(11+11)-(7+9)>0

27 JAN

	+	.	-	
+	4	0	2	6
.	0	0	0	0
-	1	0	5	6
	5	0	7	

(4+5)-(1+2)>0

28 JAN

	+	.	-	
+	8	0	10	18
.	0	0	0	0
-	8	0	9	17
	16	0	19	

(8+9)-(8+10)<0

10 FEB

	+	.	-	
+	9	0	9	18
.	0	0	1	1
-	3	1	9	13
	12	1	19	

(9+9)-(3+9)>0

13 FEB

	+	.	-	
+	6	0	2	8
.	0	0	0	0
-	0	0	8	8
	6	0	10	

(6+8)-(0+2)>0

14 FEB

	+	.	-	
+	2	0	2	4
.	0	0	0	0
-	2	0	2	4
	4	0	4	

(2+2)-(2+2)=0

15 FEB

	+	.	-	
+	3	0	2	5
.	0	0	0	0
-	1	0	4	5
	4	0	6	

(3+4)-(1+2)>0

TOTAL

	+	.	-	
+	59	0	45	104
.	1	1	1	3
-	26	1	63	90
	86	2	109	

(59+63)-(26+45)>0

VERTICAL ANALYSIS

8 JAN	11 JAN	15 JAN	25 JAN	27 JAN	28 JAN																																																																																																																								
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Fig. 2 Results of analysis of Fig. 1 (see text)

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3.5 Echo sounding observations

By comparing the distribution of fishes within a net and echo sounding records before and after shooting, it is possible to deduce the behaviour of sardines as the net is shot. There was a drop in the number of schools above the depth of the corkline after shooting which suggests that the fish move downwards as the nets are shot.

4 BEHAVIOUR OF FISH IN AND AROUND TRAPNETS

Leader nets are set to lead fish into the trapnet of which about 15,000 are to be found in the Japanese coastal fisheries mainly catching yellowtail. Formerly, the leader net was generally of straw material with a mesh of 35 to 45 cm, far larger than the girth of the fish. Fish may swim 300 to 3000 m along the leader net. Most of the information on fish behaviour has been obtained by diving and indirect methods on the leader net, rather than on the main part of the trap net.

4.1 Sardines

If in large schools sardines move along the leader net, sometimes at some distance from it. The distance swum along the net is generally greater if the current is against them. Schools swimming offshore near the surface move down immediately to about 10m when they encounter the leader net.

4.2 Yellowtail

Large schools generally move more slowly than small ones before they reach the leader net. If the schools encounter reefs or anchor ropes they sink and swim deeper than usual. Observations from the tops of hills near the trapnet has shown that after a school meets the leader net it swims along it keeping about 15m away from the net, then suddenly sinks down before reaching the mouth of the net at a distance of 70 to 150m from it.

4.3 Other behaviour

Schools of fish when frightened by other fish may swim through the meshes of the leader net while small schools may even pass back and forth through the meshes. Schools of the same species on either side of the net may pass through to join each other. A large school approaching the leader net cannot always change direction sufficiently rapidly to take up a parallel course and some fish may pass through the meshes. The remainder of the school, after some disorientation, will finally swim through the meshes and join up again. Schools of tuna may pass in either direction along the leader net while sardine schools usually go one way.

Formerly, when a trap net was constructed of straw netting with a large mesh, yellowtail would sometimes escape through the meshes. Tuna, which are usually wary of approaching netting, might then follow the yellowtail.

Schools of fish after entering a trapnet disperse into smaller schools. This may reduce the escape rate from the net.

Salmon fishermen use leader nets of cotton or manilla twine with a small mesh. The fish swim close to the net and occasionally become enmeshed. However, with a net of straw material with 6 to 8mm diameter twine and 30cm mesh the schools move along it at a distance of 1 to 1.5m and rarely pass through the meshes.

Horse mackerel move generally at 5 to 20m from the net at a depth of about 10m; of about half the fish observed, 30 percent passed into the mouth of the trapnet and 20 percent swam out again. The swimming speed varied from 0.1 to 0.55 m/sec (average 0.27 m/sec) entering the net and from 0.05 to 0.35 m/sec (average 0.20 m/sec) when swimming out.

TABLE I - Relative rate of catch in different positions of bag nets (see Fig.3)

		Net A				Net B			
Position of bag		I	II	III	IV	I	II	III	IV
Bream	Number of catch (ratio)	1	2.45	2.45	1	1	1.6	1.6	1
	Amount of catch (ratio)	1	3.50	3.50	1	1	1.8	1.8	1
Perch	Number of catch (ratio)	1	3.2	3.2	1	1	1.7	1.7	1
	Amount of catch (ratio)	1	4.0	4.0	1	1	2.0	2.0	1
Flat fish	Number of catch (ratio)	1	3.8	3.8	1	1	2.2	2.2	1
	Amount of catch (ratio)	-	-	-	-	1	2.5	2.5	1
Shad	Amount of catch (ratio)	-	-	-	-	1	2.5	2.5	1
Crab	Amount of catch (ratio)	1	0.6	0.6	1	1	3.4	3.4	1
Cuttle fish	Amount of catch (ratio)	-	-	-	-	1	1.5	1.5	1

TABLE II - Relative rate of catch of fish in nets of different materials and colours

Bag net and colour	Bream	Perch	Shad	Flatfish	Sharp-tooth eel	Eel
Cotton tarred (black)	1	1	1	1	1	1
Cotton cutched (brown)	1.5	1	-	-	-	-
Cremona cutched (brown)	2.1	1.5	-	-	-	-
Cremona (white)	2.6	1.5	1.3	2.4	0.17	0.17
Nylon (white)	3.5	2.8	1.4	2.4	0.17	0.17
Nylon (blue)	4.2	2.8	-	-	-	-

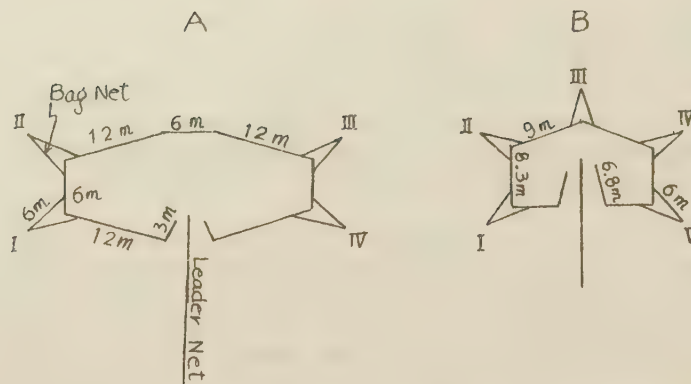


Fig. 3 Plan of "masu-ami" nets used for experiments

4.4 Catching positions in bagnets

About 4000 small bag nets or "masu ami" now operate along the coast of Japan. A plan of them is shown in Fig. 3. Miyamoto (1954) plotted the positions of capture of fish within these nets. These are shown in Table I, the results indicating that more fish were caught on the seaward side,

4.5 Colour of bagnets

Miyamoto also used materials such as cotton, nylon and cremona for bagnets. The relative catch with these nets is shown in Table II. The coastal fish such as bream, perch, shad, yellowtail and flatfish were taken better by the light nets and nocturnal species such as the eel and sharp-toothed eel by darker nets. Crab and shrimp were not affected.

5 REFERENCES

- Koike, A., K. Kanda and N. Ogura, A preparative study with trout for the gill-net.
1958 Bull.Jap.Soc.scient.Fish., 24:5-8
- Miyamoto, H., How do fish select positions and kinds of the bags of "Masu-ami"?
1954 1. Experiments with the black porgy, Sparus swinhonis Gunther. Bull.Jap. Soc.scient.Fish., 19(4):243-57
- Miyamoto, H. and E. Shiota, How do fish select positions and kinds of the bags when entering into "Masu-ami"? 2. Field tests with the sea bass, Lateolabrax japonicus and several other species. Bull.Jap.Soc.scient.Fish., 19(10): 1032-46
- _____, How do fish select positions and kind of the bags when entering into
1954(a) "Masu-ami"? 3. Field tests with flatfishes, eels and other marine animals. Bull.Jap.Soc.scient.Fish., 19(11):1109-22
- Niwa, S., On the behavior of sardine observed by fish finder. Rep.Niigata Fish.Res.Stn
1952
- Nomura, M., On the behavior of fish schools in relation to gillnets. In Modern fishing gear of the world, edited by H. Kristjonsson, London, Fishing News (Books) Ltd., pp. 550-2
- _____, Studies on gillnets. 1. Performance of gillnets and reaction of fish
1961 to the net. Bull.Tokai Fish.Res.Lab., (30):9-56

THE BEHAVIOUR OF DEMERSAL FISH IN THE PATH OF A TRAWL

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Abstract

The failure of a newly designed high headline trawl to catch demersal fish in proportion to its increased mouth opening led to a series of comparative fishing experiments. These experiments were designed not only to try to explain the failure but also to illustrate the effect of differing otter board spreads, bridle lengths and bridle angles on the catch of any trawl. At a certain point in the series an hypothesis was put forward involving the swimming speed and endurance of the fish to explain the results up to that time. Later experiments, despite some conflicting results, tend to confirm the hypothesis, and throw some light on how the configuration of otter boards and bridles shepherd fish into the path of a trawl.

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COMPORTEMENT DES POISSONS DE FOND SUR LA TRAJECTOIRE D'UN CHALUT

Résumé

Etant donné qu'un nouveau chalut à grande ouverture verticale n'avait pas obtenu en matière de capture de poissons démersaux des résultats proportionnels à l'accroissement des dimensions de sa gueule, on a procédé à une série de pêches comparatives. Celles-ci visaient non seulement à fournir une explication de l'échec enregistré, mais également à déceler l'influence exercée sur les prises de tout chalut par la modification de l'angle d'incidence des panneaux, de la longueur des bras, et de l'angle de ceux-ci. Durant les travaux a été avancée une hypothèse qui faisait intervenir la vitesse de nage et l'endurance des poissons pour expliquer les résultats obtenus jusqu'à là. Les essais ultérieurs, malgré certains résultats contradictoires, tendent à confirmer cette hypothèse, et éclairent quelque peu la manière dont la configuration des panneaux et des bras rassemble les poissons devant le chalut.

EL COMPORTAMIENTO DE LOS PECES DEMERSALES EN EL
TRAYECTO RECORRIDO POR UNA RED DE ARRASTREExtracto

El fracaso obtenido con una red de arrastre construida recientemente, de relinga superior alta, en la captura de peces demersales, en proporción a su gran apertura de boca, condujo a la realización de una serie de experimentos de pesca comparativa. Con éstos se trataba no sólo de explicar el fracaso sino también de comprender el efecto de distintas reparaciones de las puertas, longitudes de las malletas y ángulos formados por éstas en las capturas efectuadas por cualquier red. En un punto determinado de la serie se expuso una hipótesis que implicaba la velocidad de natación y la resistencia de los peces con objeto de explicar los resultados hasta aquel momento. Experimentos posteriores a pesar de algunos resultados contradictorios, tienden a confirmar tal hipótesis y arrojan cierta luz acerca del modo en que la configuración de las puertas y de las malletas contribuye a mantener los peces en el camino que recorre la red.

1 INTRODUCTION

The so-called "small Granton" trawl with a headline of 24.4 m and a groundrope of 36.6 m, used with single wire bridles 46 to 73 m in length, has served the British distant-water trawler fleet well for over 30 years. This gear proved adequate when the stocks were at a high level in 1945 and continued to do so until about 1959; by then the reduction in catch per effort and the increase in costs had made British trawler owners anxious to acquire a more efficient net. The British Trawlers' Federation, the White Fish Authority, and the Government Fisheries Laboratories of the United Kingdom (at Lowestoft and at Aberdeen) embarked on a cooperative project aimed at achieving a new net which:

- (a) had a considerably greater headline height
- (b) was somewhat greater in horizontal spread
- (c) required little or no extra power to tow it, compared with the small Granton trawl.

A contract for the necessary study and design was placed with the Saunders-Roe Division of Westland Aircraft Limited (SARO). After first designing a range of instruments the SARO team next measured the dimensions, forces and loads in the Granton gear under a wide range of fishing conditions. Finally, after tank-testing models, they designed and tested at sea new curved otter boards having a superior shear:drag ratio to the existing flat otter boards, and a new net. Features of the SARO trawl included 73 m double bridles, a wedge of netting between the upper and lower panels, a short square, and long wings, headline and groundrope.

Two commercial trawlers, the COLDSTREAMER and ROYAL LINGS of Northern Trawlers, Grimsby, were chartered early in 1963 to fish the new SARO gear against the small Granton gear on Arctic fishing grounds. Scientific observers went on both ships to ensure that the test was a fair one and to weigh and measure the catches. The comparative fishing technique used was that the two ships towed at the same speed, on parallel courses 500 to 800 m apart, and shot and hauled together; hauls where either net was damaged were not included in the analysis. The catches of each species were weighed separately and some samples were measured; after a number of hauls the gears were changed between ships to remove any bias due to the ship or the skipper.

Instruments showed that the mean distances between the trawl otter boards were: SARO 70 m, Granton 56 m. The mean distances between the wing ends were: SARO 21.3 m, Granton 16.8 m. The headline height of the SARO gear ranged from 4 to 5 m, while that of the Granton ranged from 2 to 3 m. Thus the mouth opening of the SARO trawl was 2 to 2½ times that of the small Granton, and the width of the path swept by the whole gear was about 25 percent greater. However, the catches of the two trawls were to all intents and purposes equal.

A second comparison by the same two ships in March 1963 gave much the same result. The SARO gear caught appreciably less fish than the small Granton in daylight but somewhat more at night, so that over the whole cruise there was little to choose between them. Thus it was apparent that, despite having achieved a net which had a much greater mouth opening, it caught no more fish. Further, it appeared that the SARO gear took about 4 percent more fuel to tow it than the small Granton.

The new gear was of no immediate use to the industry, but it has been used in the necessary follow-up experiments undertaken by the White Fish Authority and the Fisheries Laboratories to try to explain, in terms of fish behaviour, why the new net had failed to take fish in quantities commensurate with its increased mouth opening. Over the past four years the comparative fishing experiments mounted have shown that no quick explanation was to be obtained, each result posing yet more questions. However, these experiments were planned as an overall series and some patterns are now beginning to emerge.

The early experiments in the series included catch comparisons of Granton trawls rigged as follows:

- (a) with normal and with SARO otter boards at the same distance apart
- (b) with the same net spread and bridle lengths but different bridle angles of attack provided by different sizes of flat otter board
- (c) with the same net spread and same bridle angles of attack, but different bridle lengths and different spreads between otter boards.

After these experiments a working hypothesis was put forward to explain the results. Subsequent experiments have been conducted primarily to learn more about the effect of otter boards and bridles on the capture of fish, but these results, together with those of the earlier experiments, are applied here for testing the hypothesis.

2 THE HYPOTHESIS

The potential catch of any trawl fitted with bridles consists of two parts: "A" those fish lying in the path of the net itself, and "B" those fish lying outside the path of the net but between the paths of the wing ends and of the otter boards. The "B" group, which for most modern trawls is potentially about twice as numerous as the "A" group, will augment the catch only if they can be induced to move into the path of the net by the action of the otter boards and bridles. For effective shepherding the bridles must be long enough to allow the fish disturbed by the passage of the otter boards sufficient time to swim into the path of the net. If the towing speed is too great, or the otter board spread excessive, these fish will not be effectively shepherded. Also, if the fish are sluggish, the gear may catch no more than a bridle-less otter trawl of the same dimensions.

The catching action of a trawl comprises two separate and often opposing components: the fish's reaction to the otter boards and bridles, and its reaction to the net itself. Light enhances the shepherding effect but increases net avoidance; darkness reduces shepherding but also reduces net avoidance.

If the hypothesis is true, the following is possibly what happens when a trawl comes along. A fish in or near the path of the otter board flees randomly. If it turns outwards it escapes, but if it turns inward two things happen. Firstly, as it flees, other fish, possibly made uneasy by the passage of the ship but as yet unaware of the direction from which danger is approaching, join it, provided that they can see it or sense its hectic activity. Such behaviour can be seen in any trout stream - a frightened fish will start a stampede among hitherto resting fish. Thus each otter board sets in motion a school of increasing size. Secondly, only if this school flees within a certain range of angles from the otter board will it reach the net path before the fright "wears off". In this connection we must assume that, except by day in fairly shallow water, the bridles do very little to contain the fish, and within the range of 10 to 30 degrees their angle of attack has no effect on the catching power of a trawl. The evidence for this assumption comes from seining, which is normally effective only in daylight, and in which the angle of attack of the warps changes from almost 90° to 0° as the haul proceeds. Moreover, since after a short spurt a frightened fish will slow down or stop, it follows that, if the otter boards are very far apart, fish frightened by them will stop before reaching the path of the net. If the otter boards are close together, a fish could, in theory, spurt across the path of the net and escape on the other side. However, there are the fish fleeing from the other otter board to consider. Ideally, if the bridle length is correct the two otter board-disturbed schools should meet in the mid-line of the net with each other and with the "A" group, some of which may have been scared by the approach of the net itself. Then while general panic prevails the net will come along and scoop some of them up. In short, for each and every condition of light, size and physiological condition of the fish, there is an optimum otter board spread combined with a certain bridle length to ensure proper shepherding. If shepherding were perfect, the trawl would need no wings; as it is normally less than perfect some wing is useful. By day excessive net spread will gain very little, but by night it could be very useful indeed. Nevertheless, however good the shepherding action may be, the fish are not yet caught.

Of the combined school in front of the groundrope, which consists of $A + (B - Y)$ (Y being those that were not shepherded), a further portion " X " will avoid the net. Thus the final catch is $A + (B - Y) - X$. If the shepherding is good, Y will be low, but quite independently X can be high, and by day in clear shallow water it may be so high as to cancel out most of the benefit derived from good shepherding. By night the value of Y increases because the otter board-disturbed fish, being unable to see each other, tend to move independently rather than as schools, and in any case they are not likely to be so alarmed by vibration alone as by vibration plus sight, and so are more prone to stop after a short initial spurt and thus fail to reach the net's path. Those that do reach the net, as well as the A group already there, being unable to see the net at night, are less likely to avoid it. Thus we have night fisheries and day fisheries, and somewhere the catches by night and day are not so very different, depending on the relative values of X and Y . The traditional success of dusk and dawn hauls could be because there is then just enough light for fish to react as schools, but not enough for them to get any clear indication of the extent of the net, so that both Y and X are low and the catch is increased.

3 THEORETICAL CONSIDERATIONS RELEVANT TO THE SAUNDERS-ROE TRAWL

If such a theory has the germ of truth in it, what results would we expect from gear alterations?

3.1 Increasing the physical dimensions of the net

Increasing the physical dimensions of the net must increase A and may also help to reduce X by increasing the distance a fish must swim in order to reach the edge of the net. The catch may or may not increase linearly with net size, except perhaps at night, but it is very difficult to see how increased net size in itself can reduce catch. Only when the net becomes so huge that the noise from the engines of the trawler and vibration of the warps are well above normal might one expect fish to scatter before even the otter boards reached them. The drag of the Saunders-Roe gear is not much higher than normal, so this factor can probably be discounted as an explanation of the performance of the SARO trawl. The different shape of the SARO net, especially the reduced overhang, could however in daylight increase X even to the point where the increase in A was cancelled out, but by night the bigger net should catch more.

3.2 Increasing the spread of the otter boards

Increasing the width apart of the otter boards by extra spreading force, thus increasing B , will do little or nothing to augment the catch at night and will only augment the day catch if the fish can be induced to move the greater distance to join A . If the bridles were fish-proof fences all would be well, but on the assumption that they are not, increasing B will also increase Y . There are two reasons for this: firstly, the range of angles over which a fish must flee if it is to reach A will be reduced, and, secondly, the increased distance to the net's path increases the possibility of a fish stopping before it gets there. Therefore, although total catch may increase, the catch per unit of otter board spread should fall off as the distance between otter boards increases. Blaxter and Dickson (1959) have shown that as the size of the fish increases its swimming speed increases but its endurance when swimming at near maximum speed falls off. We might then expect trawls with very big spreads between otter boards to harvest fewer of the smaller fish, since it is likely that it is the distance covered in the initial spurt which decides whether the fish reaches the path of the net or not. Therefore, if the hypothesis is correct, one would expect the length compositions of the catches of the two trawls to be somewhat different, and the ratio by which the Granton outfishes the SARO gear would be greatest when the fish are small and least when the fish are big, especially in daylight. By night this effect should be less noticeable, since the effect of otter boards is much reduced in darkness, when fish of the A group form the bulk of the catch.

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3.3 Increasing bridle length

Increasing bridle length while maintaining the same distance between otter boards should increase the catch by giving the B fish more time to cover the distance from otter board to net path, and if small fish have relatively more endurance though less speed (Blaxter and Dickson 1959), one might expect the trawl with the longer bridles to take a higher proportion of small or slow-moving fish.

4 COMPARISON BETWEEN ACTUAL RESULTS OF COMPARATIVE FISHING EXPERIMENTS AND EXPECTED RESULTS ACCORDING TO THE HYPOTHESIS

From measurements taken with instruments during the tests we can draw a scale plan of the otter boards, bridles and net.

Next we can discover the range of angles between which a fish must flee from the otter board if it is to reach the path of the net in time to be caught. To do this we need an estimate of its speed and endurance. From Blaxter and Dickson (1959) we have:

- (a) a cod of 0.6 m in length becomes totally exhausted after swimming 80 m at 2 m/sec
- (b) a haddock of 0.3 m is exhausted after swimming 82 m at 1.75 m/sec.

Since it is most unlikely that any fish would completely exhaust itself in its initial flight we will assume that a medium-sized round-fish will travel 40 m at 2 m/sec before it stops. By drawing two arcs on the scale plan proportional to 40 m from the otter boards to out the centre-line of the net we can measure this range of angles, termed the "catch angle". Here reference is made to the centre-line of the net instead of, more correctly, to the edge of the net path, simply for purposes of convenience. Since only those fish in the 180° arc towards the net have any chance of being caught the catch angle/ 180 represents the chance of a fish, originally near the door, taking a course which will bring it into the path of the net within 40 m. Catch angles and their percentage of 180° for various gears are given in Table I.

This percentage chance of swimming into the path of the net we next multiply by the distance between the otter boards to give a number proportional to the effective shepherding potential of the gear, here called the "shepherding efficiency". This is necessary to allow for the increase, with increasing door spread, of the numbers of fish which, although not themselves frightened by the doors, nevertheless join the door-disturbed fish in flight. The "shepherding efficiency" of the various gears used is given in the final column of Table I. It is interesting to note that, in Table I, for a net fitted with 73 m bridles, the optimum otter board spread would, according to the hypothesis, be between 50 and 55 m, which is in fact the sort of spread that most skippers have tried to obtain for many years.

Net avoidance is much more difficult to assess numerically. Without adequate data one cannot know the effect of headline height. Therefore we can only assume that there were some 40 percent more fish in the path of the SARO net, since the wing-end spread was found to be 21 to 22 m as compared with 15 to 16 m in the small Granton. The benefit of the wider path swept by the SARO net will be felt most at night. Until there is evidence to the contrary, we must assume that the ability of fish to avoid the two nets under test was the same.

We are now in a position to "forecast" the results of each test, but must bear in mind that rather arbitrary values have been taken for fish swimming speeds and distances and that the significance of the answers obtained in comparative fishing experiments is often in considerable doubt, so that a perfect fit between the expected and the observed results would not be expected. Much of the work relating to shepherding has been done in Arctic winter, whereas to show the effect most clearly it should have been done in summer. On some cruises where we were testing shepherding differences, the nets used were not identical and even codend mesh sizes were different, so although we were testing Y, the X component was different for the gears under test.

TABLE I - The theoretical shepherding efficiencies of trawls

Bridle length m	Otter board spread m	Bridle angle degrees	Catch angle degrees	Catch angle as percentage of 180°	Shepherding efficiency
(a) Based on a 40 m initial flight of fish at 2 m/sec and a trawling speed of 1.5 m/sec					
73	30	5	136	75.5	23
73	35	7	128	71.1	25
73	40	9	120	66.7	27
73	45	11	111	61.7	28
73	50	13	103	57.2	29
73	55	15	95	52.8	29
73	60	17	84	46.7	28
73	65	19	71	39.4	25
73	70	21	57	31.7	22
73	75	23	39	21.7	16
73	80	25	1	0.5	0.4
73	85	27	0	-	0
3	20	25	134	74.4	15
32	44	23	85	47.2	20
128	88	16	0	0	0
(b) Based on a 80 m initial flight of fish at 2 m/sec and a trawling speed of 1.5 m/sec					
3	20	25	134	74.4	15
32	44	23	103	57.2	25
73	60	17	120	66.7	40
128	88	10	110	61.1	49

TABLE II - Length distributions of cod and haddock caught
by SARO and Granton trawls, January 1963 (Test 1)

Length cm	Cod				Haddock			
	Numbers		Percentage		Numbers		Percentage	
	SARO	Granton	SARO	Granton	SARO	Granton	SARO	Granton
18-26	-	-	-	-	8	1	1.4	0.1
27-35	1	-	0.1	-	9	11	1.6	1.5
36-44	11	13	0.8	1.1	28	54	5.0	7.2
45-53	272	189	18.6	16.5	82	127	14.6	17.0
54-62	483	248	33.1	21.7	275	335	49.1	44.7
63-71	327	178	22.4	15.6	126	192	22.5	25.6
72-80	168	122	11.5	10.7	27	24	4.8	3.2
81-89	86	115	5.9	10.1	5	4	0.9	0.5
90-99	71	129	4.9	11.3	-	1	-	0.1
100 +	42	150	2.9	13.1	-	-	-	-
Total	1461	1144			560	749		

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This makes interpretation extremely difficult. When comparing the length distributions of the fish caught by two gears we must bear in mind that the size of the fish taken from the A school will be the same. The effect of the doors and bridles will influence only those in the B school which appear in the catch, and if the fish are sluggish then the numbers of shepherded fish may be so low that no difference in the length distributions of the catches of the two nets will be discernible.

4.1 Test 1. Full SARO gear versus small Granton; COLDSTREAMER and ROYAL LINGS, Barents Sea, January 1963

Forecast: The mean otter board spreads were: SARO 70 m, Granton 56 m. Assuming an initial fish flight of 40 m, the relative shepherding efficiencies are: SARO 22, Granton 29. Therefore by day the Granton should outshepherd the SARO gear by about 30 percent. By night, if shepherding is reduced to almost nothing, then the SARO gear should catch up to 40 percent more, due to its larger net spread, unless the avoidance factor is very different for the two nets. The length distributions should be identical by night, but by day the SARO gear should take rather fewer small fish than the Granton.

Results: Having converted the total catch quantities into logarithms, the value of the running means of the log ratios were:

Day	6 valid pairs of hauls	SARO - 0.1507, or 30 percent worse
Dusk	7 valid pairs of hauls	SARO - 0.0181, or 5 percent worse
Night	13 valid pairs of hauls	SARO - 0.0105, or 3 percent worse

The day result fits the theory very well indeed. By night the SARO results are worse than expected; this could be due to greater net avoidance or it could mean that some shepherding occurs at night. If the fish's initial spurt by night was reduced to about 80 ft the Granton gear would have a great advantage over the SARO, which the latter's increased net size could not make up.

Unfortunately the codend meshes were not of the same size: SARO 114 mm, Granton 132 mm. The consequent selectivity effect would operate against the effect expected from the theory. On only six occasions were fish measured from valid paired hauls, of which two were in darkness and four in daylight. The length distributions are given in Table II, both as numbers and as percentages.

The results are inconclusive; if anything, the Granton took more cod above 80 cm than the SARO. This might imply that the SARO is more easily avoided by big cod than the Granton, but the data are inadequate for such an analysis.

4.2 Test 2. Full SARO gear versus small Granton; COLDSTREAMER and ROYAL LINGS, Barents Sea, March 1963

Forecast: The mean otter board spreads were: SARO 69 m, Granton 55 m. These give shepherding factors of 23 and 29, or a 26 percent advantage to the Granton gear. By night one would expect the SARO net to perform better by virtue of its greater spread, which was reported as being at least 20 percent greater. As the codend mesh was the same in both nets one would expect to detect a difference in the length compositions.

Results:

Day.	10 valid pairs of hauls	SARO - 0.0816, or 17 percent worse
Dusk	7 valid pairs of hauls	SARO - 0.1295, or 26 percent worse
Night	11 valid pairs of hauls	SARO + 0.0399, or 11 percent better

Once again the day and dusk results agree well with the forecast, but the night result is not as favourable to the SARO gear as one would expect. Length measurements are available from nine valid pairs of hauls (see Table III), of which seven are in daylight. The theory is upheld; the Granton takes marginally more cod below 54 cm and haddock below 45 cm than the SARO.

4.3 Test 3. Granton with 11° bridle angle of attack versus Granton with 14° bridle angle versus Granton with 17° bridle angle, all with 73 m bridles; COLDSTREAMER and ROYAL LINGS, Barents Sea, January/February 1964

Forecast: One would expect, at most, only 23 percent difference between the daytime catches of two trawls both having 73 m bridles and otter board spreads ranging between 49 and 67 m; at night it would be even less. Differences in the length compositions would not be expected.

Results: The result of perhaps 9 percent superiority of the 17° gear over the 11°, and no discernible differences between the 14° and the 11°, makes sense in view of the low light conditions prevailing.

The COLDSTREAMER (with 17° gear) used a mean codend mesh of 118 mm, and the ROYAL LINGS (with 11° gear) a codend mesh of 110 mm. The length distributions of the cod caught are shown in Table IV. Even allowing for the small numbers of fish measured and the differences in codend mesh size, there is no appreciable difference in the size of the fish caught.

4.4 Test 4. SARO otter boards versus flat otter boards, both on 73 m single bridles and trussed Granton trawls; EXPLORER and ERNEST HOLT, March 1964

This cruise was gravely curtailed by bad weather. The only hauls worth analyzing are the nine valid pairs done on Viking Bank, where the catch consisted mainly of small haddock. The net mouth opening was maintained the same for both rigs by joining the dan lenos together with a 17 m rope.

Forecast: Since all hauls were done in daylight one would expect a substantial difference in shepherding. Divergence meter readings showed the SARO otter board spread to be around 73 m and that of the flat otter boards 58 m, so one would expect the Granton to perform better by some 50 percent. One would expect the flat otter boards to shepherd small fish more effectively.

Results: Due to the small number of hauls the value of the answer is in some doubt, but it appears that the flat doors out-fished the SARO by some 40 percent (Table V). This is in fair agreement with the hypothesis.

Codend covers were used, so we have both codend and cover catches to consider in this test. The ratios of total catches of haddock, flat otter boards: SARO otter boards, were 2.3:1 in the codend, 3.2:1 in the cover, and 3.0:1 overall. Thus it was on small fish retained by the cover that the trawl with the flat doors gained its greatest advantage. This supports the hypothesis. However, a comparison of the percentage length compositions of the catches does not confirm the trend. If anything, the SARO doors shepherd small fish better than the larger ones. If the test has been repeated with EXPLORER using the flat doors this anomaly might have disappeared.

4.5 Test 5. SARO otter boards versus flat otter boards, both on 73 m single bridles and trussed Granton trawls; EXPLORER and ERNEST HOLT, Faroes, April 1964

The first phase was a repeat of Test 4. The second phase involved small SARO cambered doors (having the same spread as flat doors) versus flat doors, both on 73 m bridles and trussed Granton trawls.

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TABLE III - Length distributions of cod and haddock caught by SARO and Granton trawls, March 1963 (Test 2)

Length cm	Cod				Haddock			
	Numbers		Percentage		Numbers		Percentage	
	SARO	Granton	SARO	Granton	SARO	Granton	SARO	Granton
18-26	-	-	-	-	1	3	0.1	0.4
27-35	-	5	-	0.4	37	63	5.2	7.4
36-44	41	93	4.3	6.7	329	439	46.1	51.3
45-53	309	479	32.2	34.5	231	233	32.6	27.2
54-62	410	567	42.7	40.9	90	100	12.6	11.7
63-71	144	196	15.0	14.1	24	17	3.4	2.0
72-80	37	33	3.9	2.4	2	1	0.3	0.1
81-89	13	13	1.4	0.9	-	-		
90-99	6	2	0.6	0.1	-	-		
100 +	-				-	-		
Total	960	1388			714	856		

TABLE IV - Length distributions of cod caught by 17° and 11° gear, January to February 1964 (Test 3)

Length cm	Day and Dusk				Night			
	Numbers		Percentage		Numbers		Percentage	
	17°	11°	17°	11°	17°	11°	17°	11°
40-44	25	8	6.1	3.0	14	3	5.3	2.2
45-49	56	34	13.8	12.8	35	18	13.2	13.4
50-54	88	59	21.6	22.2	41	17	15.4	12.7
55-59	73	53	17.9	20.0	54	35	20.3	26.0
60-64	70	51	17.2	19.2	52	21	19.6	15.7
65-69	43	33	10.6	12.4	24	23	9.0	17.2
70-74	22	11	5.4	4.2	16	4	6.0	3.0
75-79	13	3	3.2	1.1	15	7	5.6	5.2
80-84	6	5	1.5	1.9	5	1	1.9	0.7
85-89	4	1	1.0	0.4	3	3	1.1	2.2
90-94	2	2	0.5	0.8	3	1	1.1	0.7
95-99	2	4	0.5	1.5	1	1	0.4	0.7
100 +	3	1	0.7	0.4	3	-	1.1	-
Total	407	265			266	134		

TABLE V -- Length distributions of haddock caught by SARO and flat otter boards
on trussed Granton trawls, Viking Bank, March 1964 (Test 4)

Length cm	Codend				Cover				Total			
	Numbers		Percentage		Numbers		Percentage		Numbers		Percentage	
	Flat	SARO	Flat	SARO	Flat	SARO	Flat	SARO	Flat	SARO	Flat	SARO
15-19	1	3	0.05	0.3	4	1	0.0	0.02	5	4	0.04	0.1
20-24	21	23	1.0	2.5	444	214	3.8	5.9	465	237	3.4	5.2
25-29	770	356	35.7	38.1	7 769	2733	67.1	75.9	8 539	3089	62.2	68.3
30-34	398	194	18.5	20.8	2 665	520	23.1	14.4	3 063	714	22.3	15.8
35-39	383	171	17.8	18.3	607	123	5.3	3.4	990	294	7.2	6.5
40-44	304	117	14.1	12.5	69	3	0.6	0.1	373	120	2.7	2.6
45-49	191	50	8.9	5.4	3				194	50	1.4	1.1
50-54	78	17	3.7	1.8					78	17	0.6	0.4
55-59	10	-	0.5	-					10	-		
60 +		2		0.2						2		0.04
Total	2156	933			11 561	3594			13 717	4527		

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Forecast: From the theory one would expect the flat doors to outshepherd the full-sized SARO doors in the first phase by 40 to 50 percent by day, but not so markedly, if at all, by night. By day there should be a marked difference in the length compositions of the catches. In the second phase, unless there is something intrinsically wrong with cambered doors for fish-shepherding, one would expect catches and length distributions to be similar.

Results: Unfortunately in the second phase there were small but apparently important differences in the rigging of the two nets, resulting in high inter-ship differences. However, the main points of the hypothesis concerning total catch were confirmed (see Table VI).

In the first phase we have measurements of cod and haddock (see Table VII), in the second phase of haddock only. As on previous cruises, measurements only from valid paired hauls are used. In the first phase the theory once again holds for haddock, the flat otter boards showing greater superiority on fish less than 45 cm long. Most of the cod were taken at dusk or by night, which would account for the similarity in the length compositions. The haddock catches can, however, be split into day, dusk and night, to determine when the differences are most marked. The only difficulty here is how best to express the observed differences. In Table VIII are given the numbers of haddock in each length group, the percentage distributions, and finally the difference between numbers caught by the SARO and flat otter board gears, expressed as a percentage of the total number in that length group caught by both gears. In this last column any result based on a total of less than twenty fish has been omitted. By day (Table VIII (a)), the inferiority of the SARO otter boards in shepherding the smallest fish and their improved performance on the bigger fish is shown. In the dusk hauls (Table VIII (b)), the SARO otter boards seem to be 15 to 27 percent less efficient for all sizes of fish. By night (Table VIII (c)), when only three valid pairs of hauls were made, the results are in considerable doubt, but it would appear that the superiority of the SARO otter boards is greatest on the biggest fish. Although all the fish caught were measured, many more data are needed to fully investigate this aspect of trawling. There can be little doubt, however, that SARO otter boards perform badly on small fish in daylight; both EXPLORER/ERNEST HOLT cruises (Tests 4 and 5) confirm this fact, which is in accordance with the hypothesis.

The numbers of haddock caught by day, dusk and night in phase 2 are given in Table IX (a), (b) and (c). In contrast to phase 1, by day there is no obvious trend. This suggests that the trend in phase 1 was real and due to differential shepherding rather than some undetected difference in the nets themselves. By night the small SARO otter boards appear to outfish the Granton on the smallest haddock, and this advantage falls off as the size of the fish increases. However, as only two valid pairs of hauls are available this must remain in doubt. By dusk also the number of hauls is insufficient, but there is no obvious pattern in the results.

4.6 Test 6. Granton with 32 m bridles versus Granton with 73 m bridles versus Granton with 128 m bridles, each with flat otter boards adjusted to maintain bridle angle of attack at about 17°; ST. KEVERNE and ST. LEGER, Barents Sea, March/April 1964

Forecast: The mean otter board spreads for the 32, 73 and 128 m bridles were 44.0, 61.0 and 88.4 m respectively. A simple vector sum is needed in calculating from speed of fish and speed of trawl the "catch angle" for the 32 m gear, which then yields a shepherding efficiency of 20. The 73 m bridle has a shepherding efficiency of 28, while in theory the 128 m gear should not shepherd any fish to the midline of the net and therefore has the shepherding value of a bridle-less trawl, i.e. 15. The catch of the 32 m bridle gear should include more small fish than that of the 73 m gear, which in turn should catch more small fish than the 128 m gear.

TABLE VI - Values of running means (log Granton catch - log SARO catch) for five groups of fish (Test 5)

	Cod	Haddock		Saithe	Flatfish	Remarks
		Large	Small			
Phase 1, day:14 valid paired hauls	0.06 14%	0.13 36%	0.21 63%	0.20 57%	0.12 32%	Advantage to flat doors on all species
Phase 1, night:3 valid paired hauls	-0.14 -28%	-0.02 -5%	0.13 35%	-0.12 -25%	0.07 19%	No clear advantage to either gear
Phase 2, day:17 valid paired hauls	0.12 33%	-0.05 -12%	0.04 10%	- -	0.09 24%	Flat doors possibly better for cod and flatfish. No advantage on haddock
Phase 2, night:4 valid paired hauls	0.29 95%	0.05 12%	0.04 10%	- -	0.11 29%	Apparent advantage to flat doors but none significant, due to small number of hauls and high inter-ship variance

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TABLE VII - Length distributions of cod and haddock caught by SARO and flat otter boards on trussed Granton trawls, all hauls combined regardless of operating ship or time of day (Test 5, phase 1)

Length cm	Cod				Haddock				Length cm
	Numbers		Percentage		Numbers		Percentage		
	SARO	Flat	SARO	Flat	SARO	Flat	SARO	Flat	
20-24)	-	-	-	-	6	8	0.5	0.4	20-24
25-29)					5	18	0.4	1.0	25-29
30-34)	8	10	1.2	1.8	61	157	4.7	8.5	30-34
35-39)					233	460	17.8	25.3	35-39
40-44)	30	19	4.8	3.4	324	561	25.0	30.8	40-44
45-49)					303	351	23.3	19.3	45-49
50-54)	59	58	9.2	10.2	232	168	17.8	9.2	50-54
55-59)					91	69	7.0	3.8	55-59
60-64)	178	168	27.5	30.0	34	20	2.6	1.1	60-64
65-69)					10	7	0.8	0.4	65-69
70-74)	229	196	35.5	34.5	2		0.2	-	70-74
75-79)									75-79
80-84)	104	89	16.8	15.4					80-84
85-89)									85-89
90-94)	28	20	4.4	3.5					90-94
95-99)									95-99
100 +	6	7	0.9	1.2					100 +
Total	642	567			1301	1819			

TABLE VIII - Haddock length distributions by full size SARO and flat otter boards on Granton trawls (Test 5, phase 1)

Length cm	Numbers		Percentage		Numbers	Numbers	% gain or loss to SARO
	SARO	Flat	SARO	Flat	SARO - Flat	SARO + Flat	
(a) Full day - eight valid pairs of hauls							
20-24	8	10	2.1	1.4	-2	18	
25-29	8	25	2.1	3.4	-17	33	-52
30-34	42	111	11.0	15.2	-69	153	-45
35-39	92	197	24.1	27.0	-105	289	-36
40-44	87	198	22.8	27.1	-111	285	-39
45-49	65	104	17.0	14.2	-39	169	-23
50-54	40	59	10.5	8.1	-19	99	-19
55-59	27	15	7.1	2.1	+12	42	+29
60-64	14	8	3.7	1.1	+6	22	+27
65-69		4		0.5	-4	4	
70 +							
Total	383	731					
(b) Dusk and dawn - six valid pairs of hauls							
20-24	5	6	0.5	0.4	-1	11	
25-29	24	35	2.4	2.2	-11	59	-19
30-34	136	222	13.7	14.2	-86	358	-24
35-39	290	456	29.3	29.1	-166	746	-22
40-44	222	384	22.4	24.5	-162	606	-27
45-49	149	260	15.0	16.6	-111	409	-27
50-54	99	133	10.0	8.5	-34	232	-15
55-59	37	54	3.7	3.4	-17	91	-13
60-64	17	13	1.7	0.8	+4	30	+13
65-69	9	2	0.9		+7	11	
70 +	1	3	0.1		-2	4	
Total	989	1568					
(c) Night - three valid pairs of hauls							
20-24		1		0.1	-1	1	
25-29	4	10	0.4	1.1	-6	14	
30-34	147	131	12.8	14.5	+16	278	+6
35-39	325	285	28.2	30.5	+40	610	+7
40-44	266	260	23.1	28.6	+6	526	+1
45-49	199	140	17.3	15.4	+59	339	+17
50-54	141	50	12.3	5.5	+91	191	+48
55-59	50	19	4.4	2.1	+31	69	+45
60-64	16	5	1.4	0.5	+11	21	+52
65-69	3	2	0.2	0.2	+1	5	
70 +	1		0.1		+1	1	
Total	1152	903					

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TABLE IX - Haddock length distributions by small SARO and flat otter boards on Granton trawls (Test 5, phase 2)

Length cm	Numbers		Percentage		Numbers SARO - Flat	Numbers SARO + Flat	% gain or loss to SARO
	SARO	Flat	SARO	Flat			
(a) Full day - twelve valid pairs of hauls							
20-24	177	136	6.0	4.3	+41	313	+13
25-29	1262	1243	42.4	39.3	+19	2505	+1
30-34	582	645	19.6	20.4	-63	1227	-5
35-39	739	781	24.9	24.5	-42	1520	-3
40-44	157	258	5.3	8.1	-101	415	-25
45-49	33	37	1.1	1.2	-4	70	-6
50-54	17	24	0.6	0.7	-7	41	-17
55-59	14	26	0.5	0.8	-12	40	-30
60-64	3	10	0.1	0.3	-7	13	
65-69	2	4	0.1	0.1	-2	6	
70 +							
Total	2986	3164					
(b) Dusk - four valid pairs of hauls							
20-24	46	36	3.7	1.8	+10	82	+12
25-29	432	471	35.0	24.0	-39	903	-4
30-34	224	345	18.1	17.6	-121	569	-21
35-39	364	739	29.4	37.9	-375	1103	-34
40-44	109	268	8.4	13.6	-159	377	-42
45-49	28	45	2.2	2.3	-17	73	-23
50-54	23	34	1.9	1.7	-11	57	-19
55-59	8	15	0.6	0.8	-7	23	-30
60-64	6	12	0.5	0.6	-6	18	
65-69	1	1	0.1	0.1		2	
70 +							
Total	1241	1966					
(c) Night - two valid pairs of hauls							
20-24	54	20	9.1	5.0	+34	74	+44
25-29	254	153	26.0	38.3	+101	407	+25
30-34	103	64	17.4	16.0	+39	167	+23
35-39	123	106	20.8	26.5	+17	229	+7
40-44	31	40	5.2	10.0	-9	71	-13
45-49	6	9	1.0	2.3	-3	15	
50-54	6	6	1.0	1.5	0	12	
55-59	2		0.3		+2	2	
60-64	2	1	0.3	0.25	-1	3	
65-69		1		0.25	-1	1	
70 +							
Total	581	400					

Results: This is the test where the idea of a 40 m initial flight breaks down. Using this distance, as in all the other tests, the catches should have been in the ratio 20:28:15 or 1:1.40:0.75. If one uses 80 m as the fish-flight distance the relative shepherding efficiencies are 25:40:49 or 1:1.6:2.0. This is in good agreement with the observed ratios of 1:1.7:2.5. The result however does not conflict with the basic theory that long bridles are essential when big otter board spreads are used. It would be interesting to repeat this test in winter. In late March and early April the fish were obviously sufficiently active to reach the path of the net in time to be caught from a distance of 44 m; it has to be proved whether they are always so active.

The length distributions of the cod and haddock caught by the 128 and 73 m bridles are given in Table X (unfortunately no measurements were taken of the fish caught by the 36 m bridle gear). The length distributions of the cod caught by the two gears are identical. If anything there are more "small" haddock in the trawl with 128 m bridles. This is not so surprising since, in fact, the "small" haddock were nearly all over 35 cm in length and were obviously active.

4.7 Tests 7, 8 and 9. Effect of bridle angle, per se, on catches

The previous tests had indicated that otter board spreads in excess of 60 m when using 73 m bridles had a detrimental effect on catches; in daylight there was often a reduced catch of the smaller fish. In terms of the angle of attack of the bridles, values in excess of 17° seemed to reduce the shepherding efficiency. In Test 6 the bridle angle of 17° was only marginally superior to 11° and no better than 14° . At about this stage in the series of experiments it was reported that a Japanese trawl with a bridle angle of only 9° was fishing well. Further tests were therefore planned to measure the effect of bridle angle, per se, on catches. To do this the otter board spreads and mouth openings of the two nets had to be kept the same. Extensive calculations were necessary to determine the proper length of the wing of each net and the size of otter board to be used to ensure that these parameters were the same. This done, the nets and otter boards were made and a further three comparative fishing experiments, each of one month's duration, were staged using R.V. EXPLORER and R.V. ERNEST HOLT.

- Test 7 compared two Granton trawls with normal flat otter boards, one trawl having 73 m bridles with an angle of attack of $15-17^\circ$, and the other 110 m bridles and smaller otter boards to give a bridle angle of $10-12^\circ$ at the same otter board spread. This test was carried out at Faroe and east Iceland in February and early March 1965.
- Test 8 compared two SARO-type high-headline double-bridled trawls with SARO curved otter boards of two different sizes, one of the trawls having 73 m bridles at 17° angle of attack and the other 114 m bridles at 12° angle. This test was carried out at Faroe and south-east and south-west Iceland in July 1965.
- Test 9 was a repeat of Test 8 in winter, being conducted off north Norway in November/December 1966. The purpose of this test was to try to determine whether the conflicting results from Tests 7 and 8 were due to some difference in the way the Granton and the SARO gears shepherded fish, or whether it was merely a case of fish behaviour being different in summer and winter.

Forecast: In terms of the hypothesis, longer bridles at equal otter board spreads should have little effect on the catches of active fish in daylight. The "catch angle", assuming an initial flight of 40 m, will not be changed. The fact that more time elapses between the passage of the otter boards and the arrival of the net should allow more of the smaller, or slower-moving, fish to move into the path of the net. In cold water or in darkness (assuming that under such conditions the shepherding action of otter boards and bridles is much reduced) little or no effect on the catch or the size of the fish caught would be expected. Therefore one would expect to derive little or no benefit from the use of longer bridles in Tests 7 and 9 but some benefit in Test 8, especially on the smaller or less active species. Where the longer bridles do result in

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TABLE X - Length distributions of cod and haddock
by 128 m and 73 m bridles (Test 6)

Length cm	Cod				Haddock			
	Numbers		Percentage		Numbers		Percentage	
	128 m	73 m	128 m	73 m	128 m	73 m	128 m	73 m
18-26					1		0.1	
27-35	6	7	1.1	0.6	74	61	7.9	6.2
36-44	66	111	12.2	13.4	609	582	64.0	59.0
45-53	184	278	34.0	33.5	222	280	23.5	28.5
54-62	164	248	30.4	30.0	23	36	2.4	3.6
63-71	75	110	13.8	13.4	16	21	1.7	2.1
72-80	35	50	6.4	6.0	1	5	0.1	0.5
81-89	10	14	1.8	1.7				
90-99		11		1.3				
100 +	1	2	0.2	0.2				
Total	541	831			946	985		

TABLE XI - Length distributions of haddock caught by
110 m and 73 m bridles, February/March 1965
(Test 7)

Length cm	Numbers		Percentage	
	110 m	73 m	110 m	73 m
<10	-	-	-	-
10-14	607	421	3.5	2.6
15-19	1 036	579	6.0	3.6
20-24	213	77	1.2	0.5
25-29	3 165	2 573	18.3	16.1
30-34	1 829	1 743	10.6	10.9
35-39	2 551	2 552	14.8	16.0
40-44	3 908	3 699	22.6	23.2
45-49	2 900	2 967	16.8	18.6
50-54	831	987	4.8	6.2
55-59	173	269	1.0	1.7
60 +	50	81	0.3	0.5
Total	17 263	15 948		

an increased catch one would expect this to be partly due to an increase in the number of smaller fish caught.

Results: In test 7, despite exhaustive statistical analysis of the catches of cod, haddock, *Sebastes* and saithe (*Pollachius virens*), no significant difference could be found between the quantities caught by the two gears. Comparison of the length distributions of cod and haddock showed that the cod caught by the two gears were identical in length. The number and percentage of haddock in each 5 cm group are given in Table XI. The 110 m bridles yielded very slightly more haddock under 30 cm in length than the 73 m bridles, which is in accordance with the theory, but the difference is not statistically significant.

In Test 8 three main grounds were fished, Kidney Bank and Hafa Deep at Iceland, and West Bay at Faroe: Kidney Bank yielded mainly cod with some *Sebastes* and flatfish, Hafa Deep yielded mainly flatfish, and West Bay gave good catches of haddock and some flatfish. Statistical analysis yielded the following results attributable to the gear used:

- (a) At Kidney Bank the 114 m bridles were better by 1.73:1 on cod, by 2.34:1 on *Sebastes*, and by 2.30:1 on flatfish. All these results are statistically significant at the 0.01 level
- (b) At Hafa Deep the 114 m bridles were better by 1.47:1 on flatfish, this being significant at the 0.001 level
- (c) At West Bay the 114 m bridles were worse by 0.93:1 on haddock, better by 1.46:1 on flatfish, and better by 2.10:1 on *Sebastes*, but these results are not significant, due to a smaller number of valid paired hauls.

The haddock length distributions for the two gears are identical. The length distributions of cod are given in Table XII. The 114 m bridles did catch very slightly more cod under 40 cm than the 73 m gear, but the difference is not as marked as one might expect. Certainly the increased catch is not entirely due to smaller fish being shepherded more effectively.

The most commonly occurring flatfish was lemon sole (*Pleuronectes microcephalus*), and the length distributions of this species were studied in some detail. No significant differences could be found between the length distributions, but the 114 m bridles took significantly more than the 73 m bridles in all length categories.

The results of Test 9 are extremely difficult to understand, and it is almost impossible to obtain any statistically significant answer from them. On haddock there were no differences between the catches or the lengths of the fish caught by the two gears. The 114 m bridle gear caught marginally more cod when fished from the starboard side of EXPLORER and perhaps 30 percent more of medium cod when fished from the portside. The 114 m bridle caught marginally more medium cod when fished from the starboard side of ERNEST HOLT, but from the portside it caught marginally less than the 73 m bridle gear on the portside of EXPLORER.

It would therefore seem that the conflicting results of Tests 7 and 8 were due to one test being done in summer and the other in winter, rather than to some difference between the behaviour of the fish in relation to a Granton and a high headline trawl. It is probably the case that in these experiments no benefit of commercial importance was derived from the use of small bridle angles in winter, but that in summer the benefits from their use were of commercial importance for some species. .

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TABLE XII - Length distributions of cod caught by
114 m and 73 m bridles on SARO trawls,
July 1965 (Test 8)

Length cm	Numbers		Percentage	
	114 m	73 m	114 m	73 m
<20	21	10	0.9	0.6
20-29	24	12	1.0	0.8
30-39	193	93	8.2	5.8
40-49	265	162	11.2	10.1
50-59	512	348	21.6	21.7
60-69	496	396	21.0	24.7
70-79	469	335	19.8	20.9
80-89	285	183	12.0	11.4
90-99	90	54	3.8	3.4
100 +	13	8	0.5	0.5
Total	2368	1601		

5 CONCLUSIONS

The results of the early comparative fishing experiments led to the formulation of a workable hypothesis that it is the swimming speed and endurance of the fish that decides the optimum otter board spread. On four occasions in daylight (Tests, 1, 2, 4 and 5) otter board spreads of 70-80 m, when using 73 m bridles, proved less successful than spreads of 50-60 m. Test 3 showed that in Arctic winter conditions the catch was not linearly related to otter board spread at unit bridle length. Test 6, however, showed that, in spring, otter board spreads could be increased with advantage up to 88 m but only when the length of the bridles was increased to 128 m, thus reducing the angle of attack of the bridles to the normal 15-17°. Increasing the bridle angle above this range frequently led to a reduced catch. The loss of shepherding efficiency was most marked when fishing in daylight on grounds where small fish were plentiful. The commercial trials of the SARO gear suggest that at night the size of the net opening is of considerable importance.

An empirical formula, based on an initial fish-flight of 40 m from the otter boards at a speed of 2 m/sec, was tested against the observed results and gave a measure of agreement. In those tests where sufficient length measurements were available, the gear with the greater otter board spread was often shown to catch rather less of the smaller fish. In the later tests (Nos. 7, 8 and 9), increasing the length of the bridles while holding the door spreads and mouth openings constant had no beneficial result either on Granton trawls or SARO-type trawls in winter. In summer the reduced bridle angles, or, in terms of the hypothesis, the increased time allowed for the fish to move into the path of the net, had no effect on the haddock catch but improved the catches of cod, *Sebastes*, and flatfish; the length distributions showed that the catches of fish of all lengths, not just the numbers of undersized fish, were increased. This latter fact does not add weight to the hypothesis, but neither do alternative theories completely satisfy the facts. One theory is that when the otter board spread is large the eddy trails pass so wide of the wing ends that fish escape through the gap between the wing end and the cloud of disturbed particles. This theory and some observations to support it have been put forward by Martyshevskii (1966). Another theory is that at large otter board spreads the angle of attack of the netting in the wings of the net is increased and the flow of water through them lifts the groundrope

clear of the sea bed, allowing fish to escape underneath. Yet another theory is that fish will be shepherded by a wire at a fine angle but will cross a wire which approaches them at a steep angle. None of the alternative explanations accounts satisfactorily for the observed differences in the length compositions of the catches in some of these tests. Why should small fish escape more readily than larger fish between the eddy trail and the wing end, or under the groundrope? Why should small fish cross a bridle at 20-25° to the direction of tow more readily than larger fish?

Although it does not conclusively prove the point most of the evidence produced here suggests that fishes' swimming speed and endurance are the key factors in determining how many fish are caught by a bottom trawl; therefore, when fish are being shepherded, the bridles must be long enough to allow those fish disturbed by the otter boards to move into the path of the net. Somewhat greater otter board spreads may be acceptable when the fish are active but, even with the gears in current use, reduced spreads will not necessarily be detrimental if the fish are sluggish. Bigger nets can produce bigger catches at night, but if the bigger otter board spread needed to keep them open results in less efficient shepherding by day they will not be commercially acceptable.

One unfortunate conclusion is that, if bridle length must be increased when large otter board spreads are used, the danger of net damage on many worthwhile fishing grounds is increased. If a gear must have bridles of 120 m or more in length to ensure good shepherding, it may be so restricted to fine ground as to be completely impracticable commercially.

If a means could be devised of making the bridles themselves shepherd fish and yet be less liable to snag the sea bed, a relatively small net with long bridles and a large otter board spread could quite easily be designed from the knowledge accumulated in the course of these tests. Such a gear could yield improved catches in Arctic summer conditions. For winter, a large net with normal bridles and otter boards could easily be made if future tests show this to be desirable.

6 REFERENCES

- Blaxter, J.H.S. and W. Dickson, Observations on the swimming speeds of fish. J.Cons.
1959 perm.int.Explor.Mer, 24(3):472-9
- Martyshevskii, V.N., The effect of the eddy trails of the otter boards on the
1965 catching ability of trawls. Ryb.Khoz., 41(12):28-30. Also issued as
Transl.Fish.Lab.,Lowestoft, (80):5 p.
- _____, The effect of the eddy trails of the otter boards on the catching
1966 ability of trawls. Ryb.Khoz., 42(1):51-4. Also issued as Transl.Fish.Lab.
Lowestoft, (80):5 p.

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THE IMPORTANCE OF SOUND IN FISH BEHAVIOUR
IN RELATION TO CAPTURE BY TRAWLS

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Abstract

Recordings of ship and trawl noise have been analysed in the frequency band 25 to 10,000 c/s. Comparison of the spectra obtained with audiograms for marine fish show that there is sufficient energy for detection over long distances. The role of the labyrinth and the lateral-line system in hearing are discussed. The audiogram for the lythe, Pollachius pollachius, shows maximum sensitivity (-8.4 dB r e. 1 μ bar) at around 300 c/s with a sharp cut-off above this frequency. The evidence that fish respond to sound stimuli is reviewed with special reference to the processes of capture by trawls.

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L'IMPORTANCE DES SONS DANS LE COMPORTEMENT DU POISSON POUR LA PECHE AU CHALUT

Résumé

On a analysé les bruits produits par les navires et par les chaluts dans la bande de fréquences 25 - 10 000 Hz. La comparaison entre les spectres obtenus et les audiogrammes de divers poissons marins révèle que l'énergie est suffisante pour permettre une détection à grande distance. Les auteurs étudient le rôle que jouent le labyrinthe et le système de la ligne latérale dans l'audition du poisson. L'audiogramme du lieu jaune (Pollachius pollachius) indique une sensibilité maximale (-8,4 dB, réf. $1 \mu\text{bar}$) aux environs de 300 Hz, avec une nette chute au-dessus de cette fréquence. Les données établissant que les poissons réagissent aux stimuli sonores sont examinées notamment du point de vue des divers procédés de pêche au chalut.

IMPORTANCIA DEL SONIDO EN EL COMPORTAMIENTO DE LOS PECES CON RESPECTO A SU CAPTURA POR ARTES DE ARRASTRE

Extracto

Se han analizado grabaciones de los sonidos emitidos por la embarcación y el arte de arrastre en la banda de frecuencias de 25 a 10.000 c/s. La comparación de los espectros de peces marítimos obtenidos con audiogramas demuestran que existe energía suficiente para la localización a mucha distancia. Se estudia la función del laberinto y de la línea lateral en la percepción de sonidos. El audiograma del abadejo Pollachius pollachius, demuestra que la sensibilidad máxima (-8,4 dB re. $1 \mu\text{bar}$) está a cerca de 300 c/s y que por encima de esta frecuencia se reduce intensamente. Se reseñan los estudios relativos a la reacción de los peces a los estímulos sonoros con especial referencia al proceso de captura con artes de arrastre.

1 INTRODUCTION

Several authors have suggested that the sounds generated by fishing vessels and their gear affect the behaviour of fish in their vicinity. There are few reliable observations to support these views, however. The aim of this paper is to consider whether the sounds produced by fishing vessels and their nets can be heard by fish, and whether they influence the process of capture.

2 THE SOUNDS PRODUCED BY SHIPS AND TRAWLS

There is little information available on the sounds generated by fishing vessels, and even less on the sounds produced by the gear that they tow. Shishkova (1958) presented frequency analyses of ship noise under various conditions of steaming and trawling and concluded that the sound from the gear was very slight in relation to the very intense noise from the ship. Schärfe (1956), on the other hand, from studying the acoustic interference shown on echo-sounder, concluded that the bobbin groundrope of a trawl generated sounds of comparable intensity to the ship's propeller.

In 1964, in cooperation with the Admiralty and the White Fish Authority, measurements were made on the sounds produced by the research ship 'Explorer' whilst towing an Aberdeen trawl. Details of both ship and trawl are given in Table 1.

Table 1

<u>Ship</u>	F.R.S. Explorer.
Length overall	202 ft. (61.5 m)
Beam	32 ft. (9.75 m)
Draught	14 ft. (4.3 m)
Gross tonnage	800
Engine	3 cylinder triple expansion steam developing 1000 BHP at 120 R.P.M.
Propeller	Single 4-blade solid R.H. manganese bronze designed for 12 knots at 125 R.P.M.
Speed	3.65 knots.
<u>Aberdeen trawl</u>	
Material	Manila
Groundrope	84 ft. (25.6 m) fitted with 14 18 in. (55 cm) and 6 21 in. (64 cm) diam. steel bobbins separated by lancasters. Rubber disc wing bobbins.
Headline	96 ft. (29.3 m) fitted with 56 floats of diam. 8 in. (24.4 cm)
Otterboards	Rectangular Fernaught 11 x 5 ft. (3.36 x 1.53 m) 16.75 cwt.
Backstrops	10 ft. (3.05 m)
Sweep wires	180 ft. (55 m)
Wires	20 ft. (6.1 m)
Warp	2100 ft. (640 m)
Water depth	720 ft. (220 m)

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Tape recordings were made from a calibrated hydrophone placed on the sea bed as the ship and trawl passed by. The towing course was plotted on shore-based radar, and was arranged so that the trawl came within 100 metres of the hydrophone. On one occasion this resulted in part of the trawl (probably the starboard sweep wire) hitting the hydrophone - providing a recording in which noise from the trawl predominated. Other recordings were made with the trawl further away, where its noise was masked by the very intense noise from the ship.

Figure 1 gives frequency analyses of both ship and trawl noise, expressed as sound pressure level in decibels, referred to $1 \mu\text{b}$, in 1 c/s bands, over the frequency range of 25 c/s to 5 kc/s. The trawl noise was recorded from a distance of approximately 10 metres, and the ship noise from 100 metres.

The noise from the ship was composed of low frequencies, generally below 150 c/s and derived mainly from the propeller. Above 100 c/s, the sound pressure fell off with increase in frequency, though substantial energy was present at discrete frequencies, perhaps as a result of a 'singing' propeller blade. It was noticeable that ship noise was very much higher during trawling compared to free-running, probably as a result of the heavier load on the propeller.

Noise generated by the trawl was very distinctive to the ear, and was of a tinkling or rattling nature. Presumably these metallic sounds arose from loose shackles, chains and bobbins. Substantial energy was also present at low frequencies, and was probably introduced by the movement of the trawl doors, and vibration of the warps and sweeps.

The sounds recorded from the ship were of very high amplitude, and masked the sounds from the trawl over the frequency range 10 c/s to 4 kc/s except when the trawl was very close to the hydrophone. Trawl sounds were more distinctive in the frequency range of 2.5 to 5 kc/s. The high level of sound from both sources suggested that fishing vessels were relatively easy to detect over long distances using passive underwater listening techniques. This has been borne out in our studies of the sounds produced by fish, where often listening has been disturbed by trawlers operating several miles away.

3 THE SENSE OF HEARING IN FISH

Comprehensive reviews of fish hearing have been published in recent years by many authors, including Kleerekoper and Chagnon (1954), Lowenstein (1957), Moulton (1963), Tavolga (1965) and van Bergeijk (1967). A brief synopsis of these accounts is all that is necessary here.

Sensitivity to sound has been demonstrated for many species of fish by workers employing a great variety of methods. Two main sensory systems have been suggested as the acoustic receptors, the paired labyrinth organs, and the lateral-line. Collectively these are referred to as the acoustico-lateralis system.

The labyrinth organs of fish are paired structures, embedded in capsules of the skull one on each side of the head. Each labyrinth consists of three semi-circular canals, joining with a series of three fluid-filled cavities containing dense crystalline bodies - the otoliths. Experiments involving the elimination of different portions of the labyrinth have established that in the bony fishes, two of these otoliths are concerned with the perception of sounds (the saccular and lagenar otoliths - the pars inferior), while the other (the utricular otolith), and the semi-circular canals (the pars superior), are concerned with the perception of gravity, and angular accelerations (von Frisch, 1936; Dijkgraaf, 1960). It does not appear that these functions are clearly defined, however, and Dijkgraaf, and Schoen and van Holst (1950) have demonstrated that both the pars inferior and superior can only play a part in sound reception and the maintenance of equilibrium.

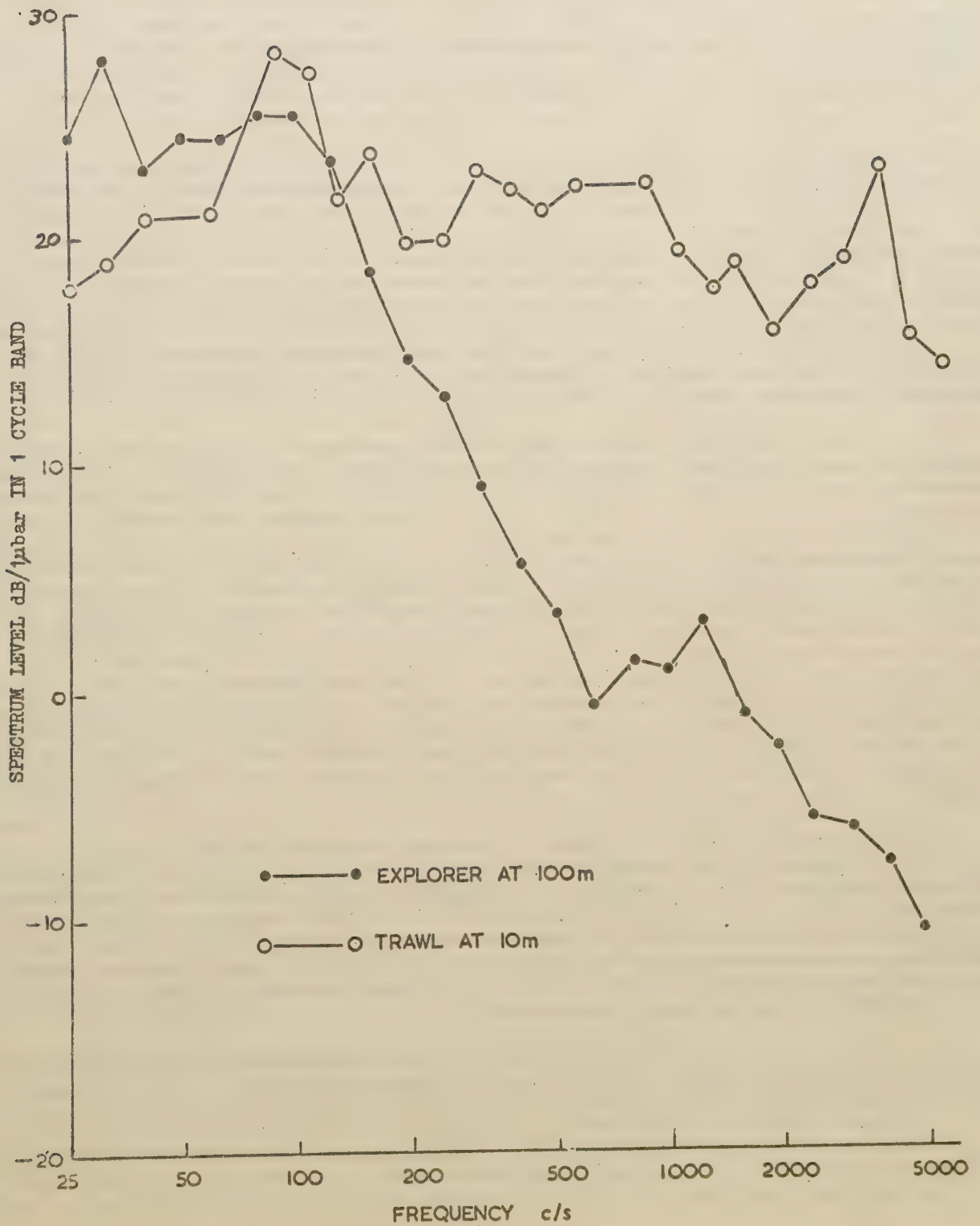


Fig. 1 Analysis of noise in the frequency band 250/s - 5Kc/s generated by the "Explorer" and by the Aberdeen trawl.

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The fine structure within these organs is that of groups of sensory hair cells, the maculae, loaded by the otoliths. These hair cells appear to be widespread throughout the acoustico-lateralis system, and to be sensitive to shearing forces. On this basis both Pumphrey (1950) and de Vries (1950) have suggested that the otoliths and their sensory cells are displacement detectors, responding to the particle displacement component of sounds.

Many fish have intimate connexion between the labyrinth system and the gas-filled swimbladder, and it has often been suggested that the swimbladder forms an essential part of the hearing apparatus in these fish. van Bergeijk (1964), Alexander (1966) and others, have suggested that passage of a sound through these fish results in volume changes of the swimbladder, which are transformed into displacements of the otoliths. This would provide a basis for detection of the acoustic pressure component of sounds. Recently, a series of elegant experiments by Enger and Andersen (1967) have indicated that this can occur even in the absence of a direct mechanical link between the swimbladder and the labyrinth. Mechanical links between the swimbladder and labyrinth are present in the Holocentridae, Moridae, Clupeidae, and in the predominantly freshwater Ostariophysi. The latter fishes are among those with the highest developed sense of hearing.

The lateral-line system of fish consists of many groups of lightly-loaded hair cells, distributed in well defined tracts on the head and flank. Some of these tracts may be enclosed in canals. Dijkgraaf (1963) has shown that these organs are sensitive to water displacements in the vicinity of moving objects. Other workers, and particularly Harris and van Bergeijk (1962), have suggested that they may also be sensitive to low frequency acoustic phenomena, and in particular to the large amplitude displacements encountered in the near vicinity of a sound source. Pumphrey (1950), and Harris and van Bergeijk have pointed out that close to a sound source (within the so-called 'near-field'), the gradient of displacement amplitude with distance is very pronounced. They have suggested that an array of displacement detectors - like the lateral-line, should in theory be able to locate the source of these disturbances. van Bergeijk (1964) has considered the evidence that several species can orientate to sound sources, in the absence of visual cues, and has concluded that this orientation is based on the directional sensitivity of the lateral-line within the near-field. van Bergeijk has also considered the role of the labyrinth organs in localising sound sources, but has concluded that there is little evidence for directional hearing.

The absolute sensitivity to sounds of different frequency has been determined for a number of different species, mainly by conditioning techniques. These experiments are made particularly difficult by the problems of transmitting undistorted low frequency sounds into small aquarium tanks. Tavalga and Wodinsky (1963) have published sensitivity curves, or audiograms, for several North American species of marine fish, and indicated that lowest thresholds were over the range of 200 c/s to 600 c/s, with the upper frequency limit to hearing at about 1-2 kc/s. Threshold values at optimum frequencies varied between -40 db/1 μ b and +20 db/1 μ b for different frequencies.

One of us (C.J.C.) has recently investigated auditory thresholds for two gadoid fish, the saithe Pollachius virens, and the lythe, Pollachius pollachius. Data are presented here for the lythe.

4 AUDITORY THRESHOLD DETERMINATIONS FOR THE LYTHE, POLLACHIUS POLLACHIUS

The apparatus and avoidance training methods used to study the hearing of the lythe were essentially those of Tavalga and Wodinsky (1963). Single fish in a small tank were trained to swim through an aperture on hearing a sound, in anticipation of an electric shock. The act of entering the aperture broke a light beam which switched off the shock. The fish were subjected to 25-40 trials per day, with 1-2 minutes between trials. Under these conditions, approximately 2 days were required to establish an escape reaction to the electric shock, and from 3-20 days to establish the same avoidance response to a pure tone stimulus presented several seconds before onset of the shock.

The sound stimuli used differed from those of Tavalga and Wodinsky, and were provided by a large loudspeaker mounted in air beneath a very thin-walled aquarium tank. The whole system was mounted inside a large fibre-glass container, lined with sound absorbant material. Parvulescu (1964) has pointed out that by producing the sound in air, rather than directly in water, acoustic near-field effects can be avoided. Pure tone stimuli were presented to the loudspeaker from a sine wave oscillator and amplifier, and were monitored within the aquarium tank by a calibrated hydrophone feeding an oscilloscope and vacuum-tube voltmeter. Sound pressure levels for the pure tones were all at least 40 dB above the level of ambient noise, and variation within the tank was within 4 dB. Once an avoidance response was established for a high amplitude sound of particular frequency, the sound level was varied for successive trials to establish a threshold for the fish. This variation followed the 'staircase' technique of von Békésy.

The results of threshold determinations, based on several fish of 23 cm length, over the frequency range 140-500 c/s are given in Fig.2. This audiogram shows maximum sensitivity at about 300 c/s, where the threshold was -8dB/1 μ b. Avoidance responses could not be established above 500 c/s.

It is clear from these figures that marine fish are capable of hearing the sounds generated by ships and their trawls, perhaps over considerable distances. The lowest thresholds of the lythe and for other species are at frequencies where the sound output of ships and trawls is high. However, the significance of acoustic thresholds derived from studies on the conditioning of fish to pure tones is difficult to assess. Very few experiments have been carried out on the conditioning of fish to acoustic stimuli other than pure tones - though the sounds encountered in the sea are often very different. It is now well established that the sounds produced by marine fish show a high degree of amplitude modulation (Brawn (1961) for the cod, Freytag (1963) for the gurnard, Hawkins and Chapman (1966) and Hawkins *et al.*, (1967) for the haddock). It is also clear that many fish respond to the onset of sounds, or to sudden acoustic stimuli, but not to steady noise, or pure tones (Miyake, 1952; Burner and Moore, 1953). It is evident that a great deal of research needs to be done on the auditory capacities of fish, to determine acoustic thresholds (not necessarily to pure tones), to determine the degree of discrimination between different sounds, and to investigate the capacity of fish to localise sound sources.

5 THE REACTIONS OF FISH TO SOUNDS

Many fish produce sounds, and it is well established that these sounds have significance in aggressive behaviour and in courtship. Other sounds, produced during swimming, and feeding, may well be significant in schooling behaviour (Moulton, 1963), and in detecting prey or predators. These sounds have been used for many years in the fisheries of several countries to detect and attract fish, and have been described by

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Fig. 2

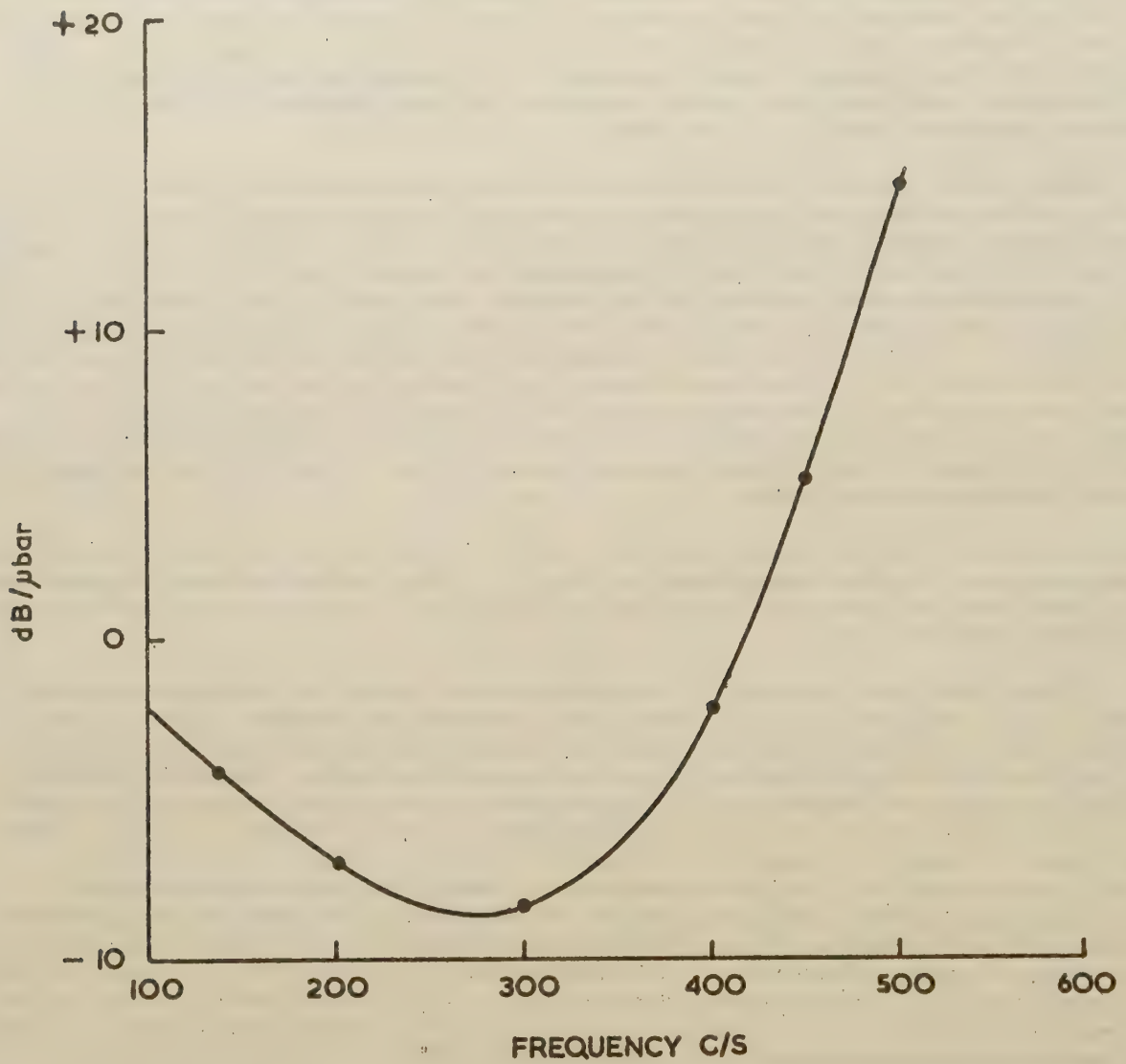


Fig. 2 Auditory-threshold data for the lythe (mean values for three specimens 23 cm. in length).

Busnel (1959) and Moulton (1963). Many of the artificial sounds used to attract fish appear to imitate natural sounds, and the importance of producing the correct stimulus to attract fish has been emphasised by Wisby *et al.*, (1964). These workers attempted to attract sharks to different types of sounds, but only succeeded in achieving a response to pulsed low frequency sounds similar to those produced by struggling or wounded fish.

Many workers have tried to elicit avoidance responses from fish, or to guide the movements of fish, by a variety of sounds. Few of these attempts have been successful, however, particularly where pure tones have been used (Burner and Moore, 1953; Miyake, 1952); Shishkova, 1958). Moulton (1964) has pointed out that the usual response of fish is one of quickened movement, or a startled response, but Burner and Moore emphasised that these movements were often very brief - the fish appearing to adjust very quickly, even to very high sound levels. Several workers have achieved consistent avoidance responses to low frequency sounds - Chapman (1964) found that herring shoals were able to avoid low frequency sound sources at close range, and obtained an avoidance to recordings of ship and trawl noise. Regnant (1927) obtained a similar response by the whiting to the low frequency vibrations of a rubber diaphragm. Both authors suggested the importance of the lateral-line of the fish in these experiments.

Protasov (1965) has described several instances of clupeoid fish diving in response to high intensity sound sources, the movements of the fish being observed on echo-sounders. We have observed similar dramatic responses of echo-traces to a sound source off the west coast of Scotland. The observations were made in Loch Torridon, from a research ship anchored over a large echo-trace, extending from 15 to 30 fathoms in water 50 fathoms deep. This trace was fished with hand-lines, and large numbers of whiting obtained (length range 20-35 cm). When a large low frequency sound source (the 'air-gun') was fired off intermittently, giving a series of high amplitude low frequency pulses, the whiting showed a sudden downward movement, forming a more compact layer below 30 fathoms. Figure 3A shows the changes in the echo-trace when the sound source was switched on.

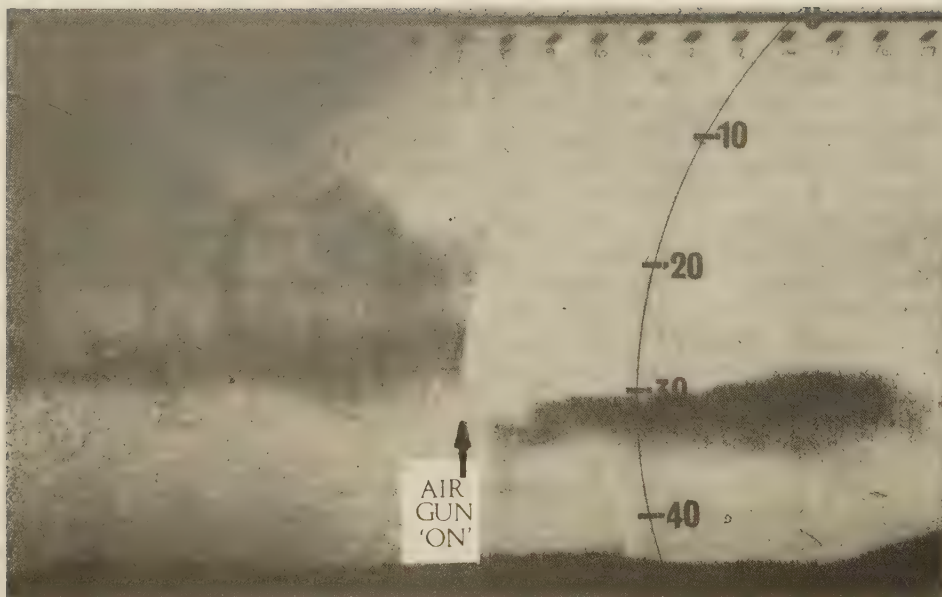
The fish were occasionally stimulated by the air gun for short periods, over about an hour. Towards the end of the experiment it was noted that the fish appeared to be habituating to the sounds. This is demonstrated in Figure 3B. Here the air gun was fired for a period, during which the fish steadily ascended. This steady rise persisted when the air gun was switched off. When the sounds were produced again, another downward response was noted.

The peak amplitude of the sounds produced by this device was approximately $120 \text{ dB}/1 \text{ } \mu\text{b}$ 1 metre away - significantly louder than the sounds produced by a ship at this distance. In addition, the sound was very brief, and was produced intermittently, so that its quality was very different to the continuous noise produced by ships and trawls.

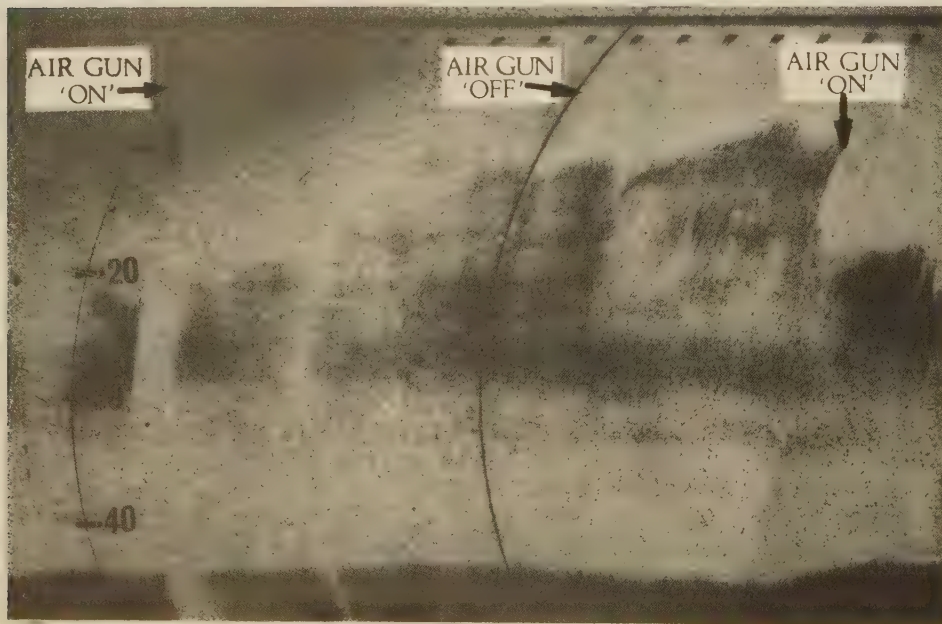
Evidence that fish respond to sound stimuli produced by trawls, is based on relatively few papers, which have described fish reacting to the approach of fishing gear in darkness, or at some distance (Schärfe, 1959; Parrish *et al.*, 1962; Mohr, 1964; Beamish, 1966). In particular, Bagenal (1958) has suggested that the efficiency of the Vigneron-Dahl trawl may be attributed to low frequency vibration of the sweeps between the otterboard and wing of the net. He has suggested that this might account for the efficacy of this trawl in darkness, where the importance of visual cues in herding fish is less.

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Fig 3



A



B

3min

Fig. 3 Echo-sounder charts showing the apparent depth changes of a shoal of whiting beneath the ship during stimulation by a compressed air sound source ("air-gun"). Depth scale marked in fathoms.

Few general conclusions can be drawn from this survey of the influence of sounds on the behaviour of fish. It is clear that fish can react to sounds, particularly where they are of high amplitude and low frequency, and where they are produced intermittently. It is also apparent from comparison of noise measurements and auditory threshold data that fish can hear the low frequency components of trawl and ship noise. However, until specific reactions can be demonstrated in response to trawl and gear sounds it is not possible to conclude that these sounds have great significance in the process of fish capture. This may reflect the general lack of information on the reactions of fish to fishing gear. Possibly the increasing use of 'netzsonde' equipment, and scanning sonar systems could be useful by demonstrating that fish can react to ships or fishing gear at some distance - where they are out of visual contact with the ship or net. Additional evidence would also be valuable on the reactions of fish to fishing gear in darkness, where visual stimuli are less important.

6 REFERENCES

- Alexander, R.Mc.N., Physical aspects of swimbladder function. Biol.Rev., 41(1):141-76
1966
- Bagenal, T.B., An analysis of the variability associated with the Vigneron-Dahl
1958 modification of the otter trawl by day and night, and a discussion of
its activity. J.Cons.perm.int.Explor.Mer, 24(1):62-79
- Beamish, F.W.H., Reactions of fish to otter trawls. Fish.Can., 19(5):19-21
1966
- Brawn, V.M., Sound production by the cod (Gadus callarias L.). Behaviour, 18:239-55
1961
- Burner, C.J. and H.L. Moore, Attempts to guide small fish with underwater sound.
1953 Spec.scient.Rep.U.S.Fish Wildl.Serv.(Fish.), (111):38 p. Also issued as
Spec.scient.Rep.U.S.Fish Wildl.Serv.(Fish.), (403):29 p. (1962)
- Busnel, R.G., Etude d'un appareil acoustique pour la pêche utilisé au Sénégal et au Niger.
1959 Bull.Inst.fr.Afr.noire, (21):346-60
- Chapman, C.J., Responses of herring to sound. In Report of the Fourth I.F. Meeting,
1964 Hamburg, 19-20 October, 1964
- de Vries, H., Physical aspects of the sense organs. Progr.Biophys.biophys.Chem.,
1956 6:207-64
- Dijkgraaf, S., Hearing in bony fishes. Proc.R.Soc.(B), 152 (946):51-4
1960
- _____, The functioning and significance of the lateral-line organs. Biol.Rev.,
1963 38(1):51-105
- Enger, P.S. and R. Andersen, An electrophysiological field study of hearing in fish.
1967 Comp.Biochem.Physiol., 22:517-25
- Freytag, G., Beiträge zur marinen Bioakustik der Nord-und Ostsee. 1. Trigla gurnardus L.
1963 der Graue Knurrhahn. Arch.FischWiss., 15, 23-33

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- Harris, G.G. and W.A. van Bergeijk, Evidence that the lateral-line organ responds to
1962 near-field displacements of sound sources in water. J.acoust.Soc.Am.,
34:1831-41
- Hawkins, A.D. and C.J. Chapman, Underwater sounds of the haddock (Melanogrammus aeglefinus
1966 (L.)). J.mar.biol.Ass.U.K., 46:241-7
- Hawkins, A.D., C.J. Chapman and D.J. Symonds, Spawning of haddock in captivity.
1967 Nature,Lond., 215(5104):923-5
- Kleerekoper, H. and E.C. Chagnon, Hearing in fish, with special reference to Semotilus
1954 atromaculatus (Mitchill). J.Fish.Res.Bd Can., 11(12):130-52
- Lowenstein, O., The sense organs. 2. The acoustico-lateralis system. In The physiology
1957 of fishes, edited by M.E. Brown, New York, Academic Press, pp. 155-86
- Miyake, I., Observations on sound production and response in tuna. 4. Reactions of tunas
1952 and other fishes to stimuli. Spec.scient.Rep.U.S.Fish Wildl.Serv.(Fish.),
(91):59-68
- Mohr, H., Reactions of herring to fishing gear revealed by echo sounding. In Modern
1964 fishing gear of the world, Fishing News International and Fishing News (Eds),
London, Fishing News (Books) Ltd., vol.2:253-7
- Moulton, J.M., The acoustic behaviour of fishes. In Acoustic Behaviour of Animals
1964 (edited by R.G. Busnel), Elsevier, Amsterdam.
- _____, Underwater sound: biological aspects. Oceanogr.mar.Biol., 2, 425-54
1964
- Parrish, B.B., J.H.S. Blaxter and W. Dickson, Photography of fish behaviour in relation
1962 to trawls. ICES C.M. 1962, Comparative Fishing Committee, (77)
- Parvulescu, A., Problems of propagation and processing. In Marine bioacoustics, edited
1964 by W.N. Tavolga, Oxford, Pergamon Press, pp. 87-100
- Protosov, V.R., Bioacoustics of fishes. Moskva, Nauka, 207 p. (In Russian)
1965
- Pumphrey, R.J., Hearing. Symp.Soc.exp.Biol., 4:1-18
1950
- Regnart, H.C., Investigation of the lateral-line sense organs of Gadus merlangus.
1927 Proc.Univ.Durham phil.Soc., 8:55-60
- Schärfe, J., Echolotungen über das Verhalten eines Heringsschwärms gegenüber einem
1956 Grundschieppnetz. Fischwirtschaft, 8(9):24-6
- _____, Forsetzung der Einsciff-Schwimm-Schieppnetzversuche mit dem F.D. "RENSBURG"
1959 in der Zeit vom 12 bis 27.9 1959 in der Nordsee. Protok.Fisch.Tech.,
61(27/28):156-89
- Schoen, L. and E. von Holst, Das Zusammenspiel von Lagena und Utriculus bei der
1950 Lageorientierung der Knochenfische. Z.vergl.Physiol., 32:552-71
- Shiskova, E.V., The reactions of fish to sound and the spectrum of trawler noise.
1958 Ryb.Khoz., (3):33-9

- Tavolga, W.N., Review of marine bioacoustics. State of the art:1964. Port Washington, 1965 N.Y., U.S. Naval Training Device Center, 99 p.
- Tavolga, W.N. and J. Wodinsky, Auditory capacities in fishes. Pure tone thresholds in nine 1963. species of marine teleosts. Bull.Am.Mus.nat.Hist., 126(2):179-239
- van Bergeijk, W.A., Directional and nondirectional hearing in fish. In Marine bioacoustics, 1964 edited by W.N. Tavolga, pp. 269-280. New York, Pergamon Press, pp. 281-99
- _____, The evolution of vertebrate hearing. In Contributions to sensory physiology, 1967 edited by W.D. Neff, New York, Academic Press, vol.2:1-49
- von Frisch, K., Über den Gehörsinn der Fische. Biol.Rev., 11:210-46 1936
- Wisby, W.J., et al., Sound perception in elasmobranchs. In Marine bioacoustics, edited by 1964 W.N. Tavolga, Oxford, Pergamon Press, pp. 255-68

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THE INFLUENCE OF FISH BEHAVIOUR ON TRAWL DESIGN WITH SPECIAL
REFERENCE TO MATHEMATICAL INTERPRETATIONS OF OBSERVATIONS ON
THE SWIMMING SPEEDS OF FISH AND RESULTS OF C.F. EXPERIMENTS

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Abstract

The paper considers the evidence to date related to the swimming speeds and endurance of fish. Alternative postulates derived from these results are considered in relation to the geometry of traditional and new trawl gears. Basic equations are developed and evaluated for certain cases.

The postulates and derived equations are compared with results of comparative fishing experiments.

The needs and relative usefulness of future studies and experimentation are discussed.

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INFLUENCE DU COMPORTEMENT DU POISSON SUR LE DESSIN DU CHALUT, ET PLUS PARTICULIEREMENT
INTERPRETATIONS MATHÉMATIQUES D'OBSERVATIONS SUR LES VITESSES DE NAGE DU POISSON
ET RESULTATS DE PÊCHES COMPARATIVES

Résumé

La communication étudie les données rassemblées jusqu'ici sur les vitesses de nage et l'endurance des poissons. Diverses hypothèses formulées sur la base de ces résultats sont examinées par rapport à la géométrie du chalut classique et de types nouveaux de chaluts. Des équations de base sont formulées pour certains cas et font l'objet d'une appréciation.

Les hypothèses et les équations qui en découlent sont confrontées avec les résultats de pêches comparatives.

Enfin, l'auteur examine les études et expérimentations qui devront être effectuées à l'avenir en comparant leur intérêt respectif.

LA INFLUENCIA DEL COMPORTAMIENTO DE LOS PECES EN EL DISEÑO DE LOS ARTES
DE ARRASTRE, CON ESPECIAL REFERENCIA A LA INTERPRETACION MATEMATICA DE
LAS OBSERVACIONES DE LAS VELOCIDADES DE NATACION DE LOS PECES
Y LOS RESULTADOS DE LOS EXPERIMENTOS DE PESCA COMPARATIVA

Extracto

Examina el autor la informacion de que se dispone hasta la fecha sobre las velocidades de natación y la resistencia de los peces. Estudia diversos postulados deducidos de estos resultados con respecto a la geometría de artes de arrastre tradicionales y nuevos. Formula y evalua ecuaciones básicas para ciertos casos.

Los postulados y las ecuaciones derivadas la compara con los resultados de experimentos de pesca comparativa.

Comenta sobre las necesidades y utilidad relativa de los estudios y experimentos futuros.

1 INTRODUCTION

Trawling can be considered as the least "scientific" of all the various fish catching methods used throughout the world. In Britain and in many other countries it remains the most productive in terms of total yield.

Sophisticated fish finding and concentrating techniques continue to make purse seining and other fishing techniques more and more promising. However, where the fish are distributed over wide areas of sea and do not naturally concentrate, trawling will continue to be an important fishing method.

On this basis it is considered that improvement in the efficiency of trawling will provide substantial benefits for many years to come.

It is essential that the whole fishing unit be considered, i.e. the ship, rigging, net, and potential catch, since these and the interrelationships between them have an important role in determining catching efficiency. There are, of course, many other factors contributing to the overall efficiency including fleet operations, optimisation of handling, boat fuel consumption, boat design, etc., but for the purposes of this paper the following frame of reference is assumed; namely, a vessel of predetermined power is available and that the distribution and species of fish in the sea and their distances from the landing port are such that bottom trawling techniques are required.

Even with these limiting assumptions, until we have a more sound understanding of the distribution, behaviour and inter-reaction of fishing gear with the fish, it will not be possible to approach fishing in the logical sequence of

- (a) choose the species of fish to be harvested
- (b) design the correct fishing gear and nets to be used, and
- (c) design the correct boat to match the needs of power required to tow or operate the particular fishing gear, accommodate the catch and provide efficient means to cover the distances to and from fishing grounds relative to landing port

The aims of this paper are to consider the various approaches to the understanding of fish behaviour in relation to catching power when a bottom trawl is used, and to formulate the equations which can be used to relate the overall geometry of the fishing gear to fish behavioural factors. Particular attention is paid to the demersal fish, cod, haddock and flatfish, since these form an important part of the British trawl fishery, but the mathematical techniques could be readily extended to cover all species provided the necessary substitutions in the general equations are made. There are so many unknown parameters that various hypotheses have been introduced, and even then the equations indicate further gaps in our knowledge that must be filled before the hypotheses can be tested and corrected in such a way that the equations developed could be used in optimisation procedures. The present equations suggest many experiments which would enhance our understanding of the subject considerably.

The ultimate test of the hypotheses and their application in practical fishing techniques should be by the use of carefully controlled comparative fishing tests. The form these should take is discussed.

Particular emphasis is placed on the arrangement of the rigging in front of the nets, and this is justified by the tantalising results both of comparative fishing tests and practical fishing experience. It has been shown that alteration in the geometry in front of the net can play an important part in total catch. For example, by increasing the length of the bridles from the net to the otterboard, allowing the spread between the boards to increase while keeping the opening of the net the same produces catch increases that are almost proportional to the increase in bridle length.

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Although there must be some limit to this improvement it is never reached in a practical case because of the increase in damage and consequent delays in net and wire replacement which occur if lengths exceed a particular value dictated by the fishing ground.

Where possible, the equations concerning the geometry of the gear and the behaviour of the fish have been kept general. Certain assumptions have been incorporated at an early stage in order to produce more meaningful conclusions and hence there is some loss in rigour. Alternative assumptions, not presented here, have been tried and providing these are introduced at a stage when the equations are general, answers can be obtained. In some cases the equations can only be solved numerically and computer facilities would be essential.

2 THE PHYSICAL AND ENVIRONMENTAL CONDITIONS RELEVANT TO THE FISH WITHIN THE RANGE OF INFLUENCE OF TRAWL GEAR

2.1 Distribution

The lateral and vertical distribution of commercially important fish in the sea is presently not well known except in certain special areas and at special times or seasons. The types of distribution can be broadly classified as follows:

Vertically,

- (a) fish occurring only on or very near to the sea bed
- (b) fish which normally occur close to the sea bed but also occur in mid water
- (c) fish which normally occur in mid water but also occur on or near the sea bed
- (d) fish which only occur in mid water

Laterally,

- (e) occur in very large concentrations separated by areas devoid of fish
- (f) occur in relatively small concentrations each randomly distributed and separated by areas devoid of fish
- (g) occur as individuals in a random distribution

There are a large number of additional possibilities, but these can be considered to comprise two or more of the above types. For example (e) or (f) combined with (g) may be commonly encountered in practice.

The practical importance of the biological or environmental causes governing the distribution (e) to (g) is the additional effect that it is likely to have on the behaviour of the fish when it is encountered by fishing gear. If, for example, the fish are "in isolation" by their nature then the same "repellent force" may also make the fish more readily influenced by the herding of otter boards or bridles. This may be balanced as the artificial concentration of fish builds up in front of the net, and the fish will have a greater tendency to escape.

In certain cases the local availability of food, or preferred food, is reported to cause concentration. If this is so, any repellent force between fish cannot in that case be particularly strong.

By far the simplest case to consider mathematically is that the fish can be treated as individuals with no repellent or attractive forces between them. This case is the one considered initially and the equations developed would need to be modified to take account of any such forces. The extreme case of the shoaling species would need to be considered in a quite different way. Comparison between the rather restricted comparative fishing results and direct observations of the cod, haddock and flatfish suggest that the assumptions are nearly enough correct, but many of the parameters could easily be measured more accurately than in the past, and with such information the final equations could be evaluated with greater precision. The remaining parameters which will always be difficult to measure quantitatively can then be extracted from the equations and applied to determine catching capacity for different species and different types of trawl gear.

Provided that fish to fish interaction is not important, then the detailed nature of the lateral distributions will not affect the derived equations provided that the number of independent concentrations (or individuals in case (g)), which are likely to be found in the area covered by one trawl path, is high enough to give statistical significance to the experimental results when compared with the theoretical predictions. Henceforth we can therefore confine our attention to details of the vertical distribution only.

Cases of special interest to bottom trawling are those of (a) and (b). The lateral distribution of these will have a considerable influence on total catching performance but providing the fish finding techniques utilised on different vessels are similar the relative catch rates will still depend on the performance of the gear. For example, if condition (e) is such that the concentrations of fish are very large in comparison with the spread of the otter boards then providing this behaviour does not automatically involve high interaction between fish, for analytical purposes, the density can be considered uniform before the trawl has an influence and thereafter can be treated as if equivalent to (g).

Even in the case of (a) and (b) above the total yield from trawling may be influenced by the opening height of the trawl since the distances above the sea bed of the higher opening trawls (say 20 ft.) is small compared to the total water column. Some mathematics relevant here are given in Appendix C. Comparative fishing experiments with high and low opening bottom trawls suggest that there is a fast fall off in fish density with distance above the sea bed (Crewe, 1965). For example, experiments on cod and haddock suggested that the density had fallen to zero by 15 ft. from the sea bed. There are obvious exceptions but clearly for a large proportion of time these species are either too far away from the sea bed to be caught by the bottom trawl or are relatively tightly packed on the sea bed. It must be noted that the comparisons above occur after any disturbing influence from the otter boards and/or sweeps, i.e. the density above the first one or two feet could have already been increased by the disturbance of the fishing gear.

2.2 Possible sources of disturbance associated with the approach of Trawl Gear

Before considering the various stimuli which can be associated with fishing gear it must be pointed out that the natural environment is not devoid of these stimuli prior to the approach of fishing gear. For example, sea noise will vary with time and clearly the stimuli from the trawl gear must pass the threshold values which are detectable by the fish as a stimulating influence before it becomes effective.

The possible stimuli taken into account can be grouped into four main categories:

- (a) noise (which also includes low frequency vibrations)
- (b) light, or bioluminescence where light intensities are low

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(c) hydrodynamic pressure effects

(d) response to changes in chemical and physical properties of the sea

(c) and (d) are extremely difficult to predict. In the former case the effect is difficult to measure accurately both from the purely physical sense, i.e. a measure of the pressure gradient in the full scale fishing condition away from the otter boards, and in the laboratory it is extremely difficult to produce suitable and controlled pressure gradients in the water with the facilities of many existing observation tanks. Very little is known of (d).

Noise and light intensities are also difficult to investigate in the laboratory because of the problems of reflection from the sides of tanks etc. Some evidence is given by Enger (1966) and Olsen (this Conference). Much more data on the optical and acoustic wavelength ranges which show a positive effect on the fish are needed.

2.3 Response of fish to stimuli

2.3.1 Effective range The intensity of the stimulus must be such that it produces a positive action in the fish if any herding is to be used to improve capture. The simplest demarcation line must be that the fish is influenced to swim away from the stimulus. The magnitude of the effect is obviously important in the herding from bridles and otter boards as, too, is the time taken for the stimulus to produce the response. The latter is tacitly assumed to be short in comparison with the time scale of the catching devices considered here.

On the basis of the four types of stimuli described in (2.2), some values of the distances at which the disturbing element can be detected have been postulated. Unfortunately, the evidence for these figures in relation to the species under consideration, is rather scant. In any case, the stated values refer to averages taken over the group of fish which respond, and further it should be noted that a proportion of fish which come within detecting range of a disturbance may not respond at all.

While the responses to the various stimuli considered are treated as being independent for the purpose of the analysis, it may well be the case that the overall response is determined by a correlation between two or more stimuli.

- (a) Light (or bioluminescence). The fish will detect a threshold change in level at a distance of 2 to 3 m from the source. This includes the otter board, mud cloud and bridle effects
- (b) Sound. Bridles will produce the sound stimulus at a distance of 3 m. The ground rope will produce some disturbance up to a distance of 10 m, the otter boards 15 m and the warps 2 m (Schärfe 1955)
- (c) Hydrodynamic effects. The important source here is the otter boards. Any pressure buildup in front of the face of the otter board will be proportional to the spreading force of the board and would be expected to vary inversely with the distance. However, experience suggests that the square of the distance is a more realistic assumption. Some approximate estimates of the minimum gradient detectable by the fish would suggest that distances of 30 to 40 ft may apply for boards of about 1 t spreading force
- (d) Physical or chemical environment

Such effects may be associated with the mud cloud which is known to be generated when a board or bridle is towed across the sea bed. However, tank tests show that the mud cloud is for the most part restricted to areas well clear of the bridles (Arlotte, 1964) and only in the case of very small bridle angles does the cloud from the otter

board diffuse into the area between the bridles. Also, it is obvious that a fish would not be affected by the physical or chemical properties of such a cloud unless it is very close to or actually immersed in the cloud, by which time it has probably escaped capture by crossing a bridle. If the cloud is bioluminescent, then the effect should be considered under (a).

2.3.2 Orientation of fish following a stimulus Studies of the orientation and direction of movement of fish when encountered by trawls have been reported by a number of authors. The consensus of opinion is that when the reaction distance of 1-3 m according to the magnitude of the stimulus is reached, the fish react quickly and take up an orientation directly away from the source. Blaxter and Parrish (1965) relate the orientation of the fish to the angle of attack of ropes, and broadly this seems to be perpendicular to the direction of the approaching object. These results are confirmed by Hemmings (1967, this Conference). In practical terms, this means that providing the fish have not been overrun either through lack of endurance or too fast an approach speed, they will ultimately collect in the centre part of the gear in front of the groundrope.

Special attention has been placed by the above workers and many others on the orientation of fish which have been accumulated in front of the path of the net. The orientations beneath the headline, and again 1 or 2 m in front of the groundrope, shown in Fig. 2.1 (reproduced from Foster, 1964) are the results of still camera underwater photographs obtained by situating the cameras at different points on the net simultaneously on a large number of hauls. The species observed consisted of herring and cod, with a predominance of herring. There appeared to be little difference in the behaviour of these two species from the photographs. Analysis of the orientations from work of this sort supports the view that in the trawling condition the groundrope has an influence up to about 3 m, and this seems to be almost exactly the same as that for the bridles. The variations according to light intensity, depth of water, speed and hence vibration and noise characteristics, is not as great as one would expect. It must be noted, however, that the bridle condition for trawling has even less relevant substantial evidence. Clearly, the values for the reaction distances applied to bridles, groundropes, and wing ends of the gear tried in the equations in the following sections are suspect, but every attempt has been made to keep them sufficiently general such that in the light of new evidence new values can be added in without radically altering their form. For example, if the reaction distance, or the direction of movement of the fish to the bridle is found to be zero and omnidirectional, respectively, then the equations can not only incorporate such values but they are partly simplified.

No attempt is made to unravel the problems of the shoaling fish since the biological information to date is necessarily even less convincing and complex, and furthermore, they are less important in the demersal commercial fisheries presently under discussion.

It is hoped that the new technologies in underwater vehicles, sector scanning, etc. will play an important role in our detailed understanding of how and when the fish react to fishing gear.

As a first approximation it is assumed that the fish will swim normally to the disturbance but with a possible variation of up to $\pm 45^\circ$. This can be partly accounted for by choosing different values of the efficiencies of the boards or bridles as shepherding devices. The hydrodynamic effects are likely to fall well within the limits suggested, but the influence from sound may not be as simple. Some rather dubious evidence suggests that in two dimensions the fish may be able to locate sound within an accuracy range of 20° , but in three dimensions this may be extended to 4 or 5 times that value.

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2.3.3 Measurement of swimming speeds of fish Records of observations on the measurements of swimming speeds of fish date back to before the end of the nineteenth century.

Magnan (1930) obtained results for about twenty species, and this has been followed up by many measurements, but nearly all were concerned with freshwater varieties. One of the most difficult problems is to distinguish between maximum speed and cruising speed, and a detailed search of the literature has not been rewarding in this context. The most comprehensive study of the relationship between speed and time was given by Bainbridge (1960), and maximum sustainable speeds over 1, 2.5, 5, 10, 15 and 20 second periods were obtained but only for certain freshwater fish. At the end of the 20 second period it was observed that a steady, relatively low cruising speed was reached. The fall-off of speed in the initial time periods is very large, and the following equation was derived empirically.

$$\log V = \alpha \log l + K$$

where V = velocity, l = length, and α and K are constants, depending on the species under investigation.

The wide variation in the values of the constants suggested the need for detailed study of the biological considerations which determine the speed of the fish, e.g. volume of muscle, circulatory and respiratory transfer, together with hydrodynamic considerations like roughness of body surface, and any Reynolds number effect.

Another approach considered the relationship between fish speed and the frequency and amplitude of the tail beat in the carangiform swimming mode (Bainbridge, 1958). This could provide a valuable aid to, and would greatly facilitate the prediction of, the swimming speeds of fish of any particular length, but the necessity of obtaining precise measurements of the tail movement, probably only possible by the use of cine film, means that sophisticated experimental tanks must be used.

Such a facility was used in the experiments of Bainbridge and the technique used was to rotate the tank at a speed up to the value at which the fish could just keep stationary.

Experiments were carried out on dace, trout and goldfish. Dace and trout gave maximum amplitudes at 5 beats per second whilst that for goldfish was 3 beats per second. The frequency tended to decrease with body length and maximum amplitude was approximately one-fifth of the body length for all species. An empirical formula

$$V = \frac{1}{4} \left[l(3f - 4) \right]$$

where V is the speed in centimetres per second, f is the frequency in beats per second and l the length of the fish in centimetres was established for the species studied.

As already noted, little work relevant to swimming speed of marine species is published, except for that of Blaxter and Dickson (1959). The facilities and samples available have been much criticised by the authors themselves, but this work provides a starting point in the analysis of the relationship between length, maximum speed, cruising speed and endurance. It has been assumed that the form of the interrelationship is similar to that derived for freshwater fishes by Bainbridge.

As a first approximation, the results provided for cod and haddock have been combined together to derive a relationship between swimming speed and length.

	Length	Body lengths swim to exhaustion	Distance travelled	Speed V_M cm/sec	Time taken assuming V_M (sec)	Average speed BL/sec	Time taken at 10 BL/sec
Cod	13	151	1,960	104	19	8	15
	52	128	6,650	152.5	44	2.9	12.8
Haddock	40	143	5,720	137.5	42	3.4	14.3

$$V_M = 1.25 L' + 87.5 \quad (\text{over a Length range of 10 to 60 cm fish}).^*$$

where V_M = speed of fish (sustained for 10 Body Lengths (BL)
measured in cm/sec.

L = Length of fish in cms.

Table 2.1 Extract from the data of Blaxter and Dickson (1959)

It is not intended to consider in any further detail the laboratory techniques for measuring fish speeds, but apart from the need for many more results, the following points are presented as a plea for consideration by experimenters if their work is to provide useful information for application to fishing gear design.

- (a) The various techniques should be directly compared and evaluated in terms of repeatability and suitability for application to a wide range of species. An agreed standard could then be universally adopted.
- (b) It is essential that arbitrary times or distances for which fish swim at maximum speed should not be chosen and recorded to the exclusion of the full information. Ideally, the relationship between distance and/or velocity as a function of time should be measured using time intervals of the smallest practical duration. There are many electronic aids of varying complexity and cost on the market which would facilitate the division of experimental time into short intervals.
- (c) The largest possible sample of fish should be tested and the history of all specimens recorded. This applies particularly in the case of the marine species, where their availability, transport, etc. may present problems. This information should supplement any additional information concerning the condition of the samples under test.
- (d) For many marine species of commercial importance, there are serious doubts concerning the suitability of any sample taken from the sea to laboratory conditions. In view of this, there is an urgent need for a method of calibrating the laboratory experiments against those speeds relevant to the natural environment. One possible solution would be the use of under-sea laboratories. While these are becoming available for researches in other underwater fields, it is doubtful that they can be made available for fisheries research immediately, except perhaps for sufficient time to provide calibrations for a limited range of the parameters and species under consideration.

*No account is taken of the variation in temperatures recorded for the experiments since these seem to have little effect within the order of magnitude of this first approximation.

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2.4 Endurance of fish when swimming away from a disturbance

Much attention has been paid to possible explanations of the relatively high maximum speeds attained by fish compared with theoretical predictions from muscle content (e.g. Boddeke *et al.*, 1959), hydrodynamic properties (e.g. Lighthill, 1960, Rosen, 1962 and Reese, 1964), and the interrelationships of oxygen balance to burst speed and endurance.

Concerning these biochemical or physiological aspects of fish, the author might as well admit to not understanding the significance of the proportions of red and white muscle on burst speed endurance or energy reserve, but in any case, the literature for marine species is somewhat limited.

The application of these studies to marine species, backed up by experimentation on these species, is urgently required. In the meantime, the relationship of endurance capability has been considered to be bound up with reserve of energy and the assumptions used in the mathematics are described by Figure 3.1.

There are still several fundamental problems unsolved. For example, can the fish recognize a fall in its potential energy and check energy expenditure whilst optimising speed to maintain station at a fixed distance from the disturbance? Or, is the reaction one of uncontrolled panic? If it is, the endurance will depend solely on the interaction between physiological characteristics and the catching environment. When the energy dissipated reaches maximum values the fish will move at less than cruising speed and will finally tend towards and reach zero speed. The former alternative has been assumed in the following theoretical work, and this is justified by accepting the limited experimental evidence on the behaviour of fish in general (e.g. Bainbridge, 1960).

2.5 The influence of trawl speed

It is known that, for a given trawl gear, the speed at which it is towed through the water has an important effect on the magnitude of the catch, and also on the catch composition by species (Chestnoi, 1961).

Engineering considerations are obviously important here, but they cannot be considered without reference to the behaviour of the fish.

Hydrodynamic disturbances which originate from the boards, including those generating mud clouds, will clearly be dependent on speed. This means that the reaction distances given in (2.3) will depend on speed. As these have been included in the equations presented below as variables, the equations will therefore have an implicit dependence on trawl speed which is otherwise included only as a multiplying factor.

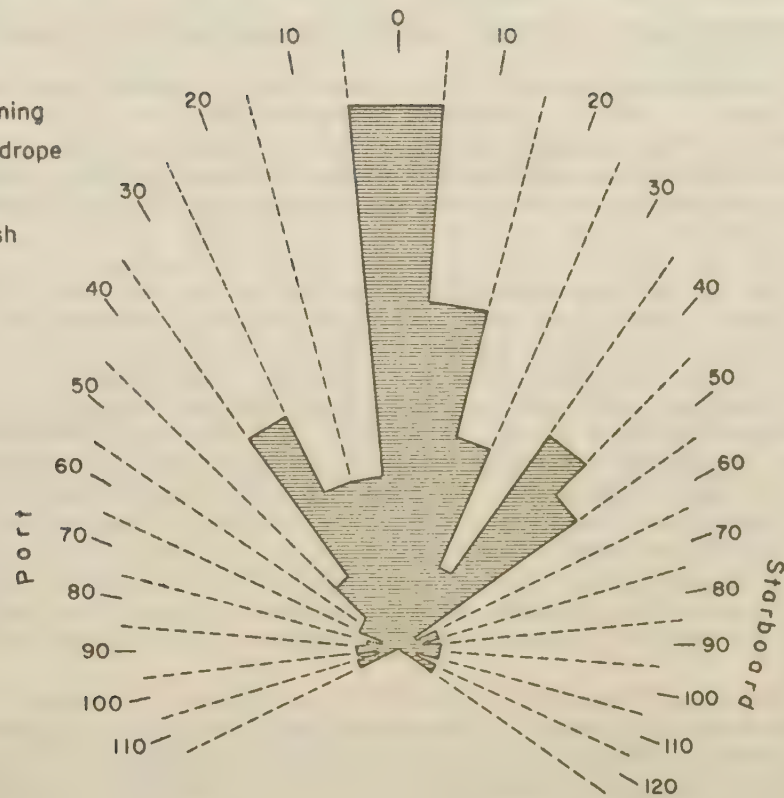
The noise level generated by the trawl, and hence the reaction distances to sound stimuli, will also depend on speed. This variation can be considered in the same way as those of the preceding paragraph.

A finite time will elapse before a fish can respond to a stimulus and so if the speed of approach of the scaring device is higher than a certain value, the fish may be overtaken before it can respond, in which case the escape probabilities will also be velocity dependent.

Escape of fish underneath the ground rope may be an important factor in determining the overall yield. This will be influenced by the extent of ground rope lifting, and it is known that the latter effect will be worse at higher speeds, depending on the nature of the ground, because of the increased time for settling after the groundrope has been raised by a bottom irregularity.

Orientations of fish swimming
just in front of the groundrope

1/4 in radius = 1 fish



Orientations of fish swimming below
the centre of the healdline

1/8 in radius = 1 fish

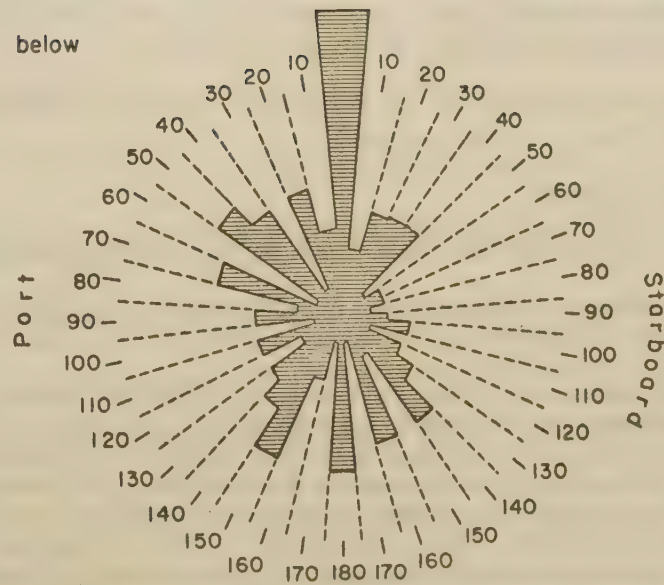


Fig. 2.1 Orientation of fish relative to direction of towing

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Incidentally the latter effect of speed will play an important role in determining the time of settlement of the gear following the shooting procedure.

2.6 Derivation of behaviour parameters from comparative fishing results

As indicated in Appendix A, the comparative fishing results described and some others that can be used in assessing possible behaviour patterns consistent with relative catches, are not quantitative. The reasons for this are described by (Gulland, 1967). Careful analysis of the data does, however, provide limiting criteria and suggests the ranges of the relevant parameters that should be investigated in more detail.

Depending on the hydrodynamic characteristics, size and shape of otterboards, there is a clear indication that variation in their soaring or shepherding properties occurs. With high spreading force values the influence may be so strong that the fish are induced to rise in level from the sea bed. Substitution of the length R_B into the comparative fishing equations not described here at values 20, 30, 40 ft indicates that 50 is too large and that 20 is too small. The equations referred to here are those related to the comparative fishing experiments described in Appendix A and have been suggested by Crewe (1965). At the same time, this R_B effect may not be important if the bridle shepherding assumptions discussed have an overriding influence not consistent with the observations described in section 2. It should be noted that the catch appears to be proportional to board spread within the bridle angle range of about 14-20 degrees, whereas at the smaller bridle angles the catch per unit board spread rises slightly and at angles greater than 30 degrees a very large reduction occurs.

Concerning the nets used independent of types of rigging, the comparative fishing results to date do not support the suggestion that net shape and size has a high bearing on catching power. The importance of continued contact of the ground rope with the sea bed, however, is clearly demonstrated by the differences in catch of flatfish compared with cod and haddock when the ground rope is known to lift off. Where this was highly evident in the test programmes described in Appendix A, there was also a marked difference in the catches of cod and haddock, haddock appearing to lie somewhere between the cod and flatfish results. This may confirm the suggestion that haddock tend to lie closer to the bottom when soared than cod. Whilst this evidence is based on rather suspect comparative results, the phenomenon has been indicated both during darkness and daylight hauls, and at different times of the year.

3 THEORETICAL CONSIDERATIONS ON FISH BEHAVIOUR IN RELATION TO SWIMMING SPEED AND ENDURANCE

3.1 General theory

In the formulation of the equations which follow, the three major assumptions are:

- (a) A fish which is stimulated repetitively will swim a finite distance before it becomes exhausted, at which point it will not respond to further stimuli.
- (b) The velocity of a fish following a stimulus bears a certain relationship to the nearness of the fish to exhaustion, which is independent of the strength of the stimulus provided that the latter is greater than a certain level. Where the exhaustion distance is finite, the "power" requirement of a fish swimming at maximum speed is greater than its production capacity, implying a certain reserve. The parameters used in the mathematical formulation of this statement are considered to incorporate effects due to oxygen balance in addition to those arising from purely "bio-mechanical" power considerations.
- (c) A fish which receives an instantaneous stimulus will then swim at a high velocity, for a distance s which may depend on its nearness to exhaustion, afterwards resting at zero velocity until the next stimulus is applied.

The last assumption is more detailed than the other two, and depends on the swimming time s/V being less than the interval between successive stimuli. However, this has been the case in some of the experiments whose results will be applied to the equations below e.g. (Blaxter and Dickson 1959), and a moment's consideration of a typical maximum fish speed compared with a typical trawl speed and geometry will show that this condition is easily satisfied under practical fishing conditions.

Consider a fish which is stimulated repetitively at an interval which is short compared with the period of observation. The stimulus is "strong" within the terms of assumption (b), and the fish spends a proportion m of the time swimming at velocity $V(t)$. The rest of the time between stimuli is spent at zero velocity while it is recovering. These hypotheses can now be combined to give the following equations:

$$\begin{aligned}\frac{dE(t)}{dt} &= -V(t) (b m V^\gamma(t) - p) \quad \text{for } E < E_n \\ &= 0 \quad \text{for } E = E_n \text{ and } V (b m V^\gamma - p) < 0\end{aligned}\quad (3.1)$$

$$V(t) = V_M + \alpha (E(t) - E_n) \quad (3.2)$$

$$E(t_e) = E_0 \quad (3.3)$$

$$V(t_e) = 0 \quad (3.4)$$

$$V_0^\gamma = (p/b m)_V = V_c \quad (3.5)$$

$E(t)$ is an "energy factor" which is related to the capability of the fish for stimulated activity. It is referred to a lower limit E_0 , and when $E(t) = E_0$ (at time $t = t_e$) the fish is exhausted. This condition is symbolized by putting $V(t_e) = 0$. On the other hand, a fully rested fish has an energy factor E_n which is an upper limit to $E(t)$.

(3.1) and (3.2) are simultaneous equations in E and V which can be solved if the following parameters are known:

- γ = the power of V which is proportional to the thrust generated by a fish swimming at speed V
- p = the recuperation factor. It is determined by the capability of a stimulated fish to return to its normal condition
- b = a factor related to the swimming efficiency of a fish, in terms of energy or other expenditures
- α = the reduction in burst velocity per unit change in energy factor
- V_M = the velocity of a fully rested fish following a strong stimulus
- V_0 = the cruising speed, i.e. a speed which can be sustained for a very long period

In the general case, p , b and α may be functions of velocity or time.

The significance of equations (3.1) - (3.4) may be more easily understood by reference to figure (3.1). Up to time t_1 , the fish is not stimulated and rests and/or swims at cruising speed. $E(t)$ remains constant at E_n during this time. Stimuli are applied between times t_1 and t_2 , which lead to the fish moving in bursts at a speed which starts at V_M and decreases correspondingly to the decrease in $E(t)$. The stimuli stop at t_2 , whereupon the velocity falls to zero and $E(t)$ recovers to E_n over a period.

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At t_3 stimuli are again applied, this time in such a way that the fish gets no rest between successive periods of motion. The previous behaviour is repeated but this time sufficient stimuli are applied to cause $E(t)$ to fall to E_0 . At this point, $t = t_0$, the fish is exhausted and the velocity falls to zero even though further stimuli are applied.

Combining equations (3.1) and (3.2) gives

$$\frac{dV}{dt} + \alpha V(b m V^\gamma - p) = 0 \quad (3.5)$$

To solve this equation the values and functional dependence of γ , b , m , p and α must be deduced or measured. In the case of m , which is dependent only on V and the applied stimuli, this is not difficult, but there is little experimental evidence available for p or α . An alternative approach is to use the above equations to derive other parameters which are easier to measure with present experimental techniques. Having applied the equations to the appropriate experimental conditions, quantitative information on the parameters in question can be obtained.

Before (3.5) can be applied to the evaluation of a practical situation, some further thought must be given to the parameters b and γ . As the term $b V^\gamma$ depends mainly on physical rather than biological concepts, we are in a better position to make assumptions about them. $b V^\gamma$ can be considered as the sum of a hydrodynamic and an inertial component. For the former, elementary hydrodynamic theory suggests that $\gamma = 2$ while b is a function of the geometry of the fish and the properties of the fluid medium, but not of V . The inertial component arises because the fish has been assumed to accelerate and decelerate once for each separate stimulus. The kinetic energy required for this is proportional to V^2 , and as it must be generated once in each time interval between stimuli, the mean power is also proportional to V^2 . The following equations have therefore assumed $\gamma = 2$ and b independent of V .

3.2 Application of the general theory to particular experimental conditions

As an example of what can be achieved by this technique, consider a fish which is subjected to strong stimuli in such a way that it is allowed no rest between bursts. The fish is fully rested at the start of the experiment ($t = 0$), but becomes exhausted after a time t_0 , during which it travels a total distance s_0 .

The condition of no rest means that $m = 1$. Further, using the definition of V_0 given in section (3.1) we have, assuming p constant

$$b m V_0^\gamma = p \quad (3.6)$$

or

$$p = b V_0^2 \quad (3.7)$$

Thus (3.5) can be rewritten as

$$\frac{dV}{dt} + \alpha b V(V^2 - V_0^2) = 0 \quad (3.8)$$

The solution of (3.8) subject to the condition $V = V_M$ at $t = 0$ is

$$V(t) = V_0 \left[1 - \left(1 - \frac{V_0^2}{V_M^2} \right) \exp(-2 \alpha b V_0^2 t) \right]^{-\frac{1}{2}} \quad (3.9)$$

By definition

$$s_e = \int_0^{t_e} V(t) dt \quad (3.10)$$

and so

$$s_e = \frac{1}{2\alpha b V_0} \log \left\{ \frac{1 + \left[1 - \left(1 - \frac{V_0^2}{V_M^2}\right) \exp(-2\alpha b V_0^2 t_e) \right]^{\frac{1}{2}}}{1 - \left[1 - \left(1 - \frac{V_0^2}{V_M^2}\right) \exp(-2\alpha b V_0^2 t_e) \right]^{\frac{1}{2}}} \right\} \quad (3.11)$$

Further, from (3.1), (3.3) and (3.9)

$$E_n - E_0 = \frac{1}{\alpha} \left\{ V_M - V_0 \left[1 - \left(1 - \frac{V_0^2}{V_M^2}\right) \exp(-2\alpha b V_0^2 t_e) \right]^{\frac{1}{2}} \right\} \quad (3.12)$$

Eliminating t_e between (3.11) and (3.12) finally gives

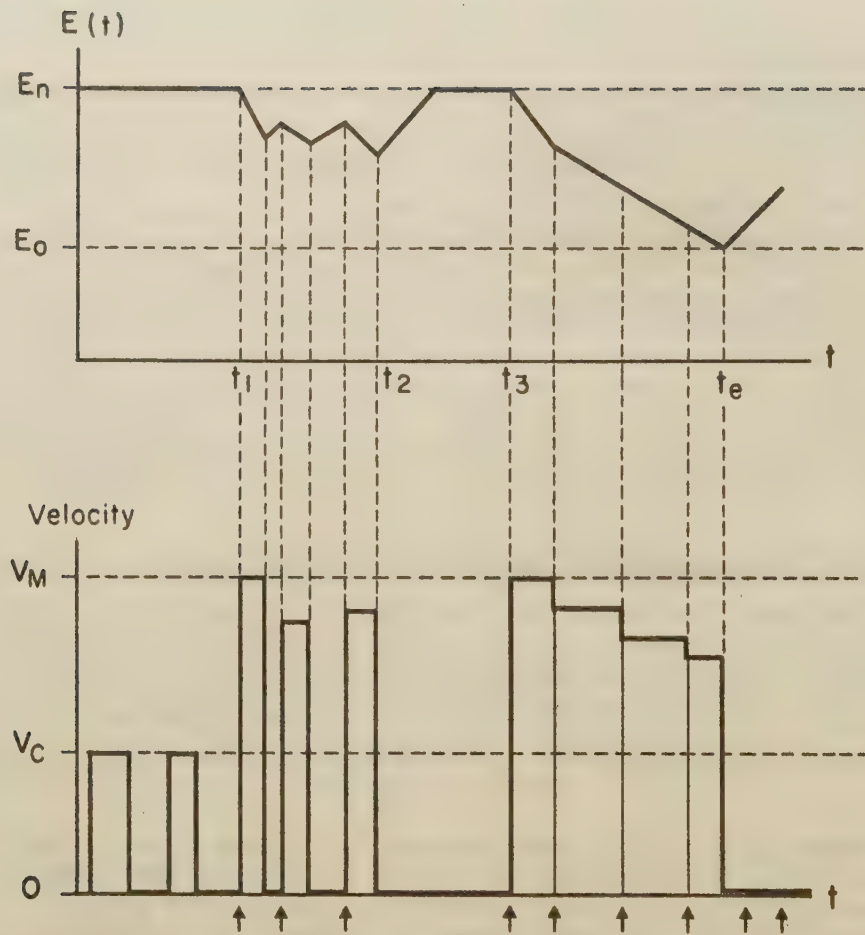
$$E_n - E_0 = \frac{1}{\alpha} \cdot \frac{(V_M^2 - V_0^2) [\exp(2\alpha b V_0 s_e) - 1]}{(V_M + V_0) \exp(2\alpha b V_2 s_e) - (V_M - V_0)} \quad (3.13)$$

Using equations (3.11 - 13), and assuming V_M , V_0 and b to be known, it will be seen that if any two of the parameters α , t_e or s_e are measured then $(E_n - E_0)$ can be determined. Hence, if it is further assumed that the latter quantity is a basic property of the individual fish which does not change with environment, the original equations could then be applied with greater precision to other situations, for example, the environment of a fishing gear.

Given the values of s_e and t_e , (3.11) can be solved to find α . Further it can be shown that α always satisfies the relationship

$$0 < \alpha < \frac{V_M - V_0}{E_n - E_0} \quad (3.14)$$

for finite and non-zero s_e and t_e . The significance of this equation is as follows. The value of α determines the decrease of burst velocity with a drop in energy factor. If α is large the velocity decreases towards V_0 so quickly that the reserve capacity for motion is never totally expended. Therefore, the fish can theoretically continue to respond to stimuli indefinitely, and s_e would not be a measurable quantity. In fact, if a particular fish were postulated to have values of α and E_0 such that



↑ represents a stimulus applied at this time

Fig. 3.1 Qualitative illustration showing the relationship between $E(t)$ and velocity for a given fish.

$\alpha > \alpha_0 = (V_M - V_0)/(E_n - E_0)$, then the quantity s_0 in equation (3.11) can be shown to have a complex value, and the equation has lost its practical value. In this case some other method would have to be used to determine α and $(E_n - E_0)$. However, we know from the observations reported by Blaxter and Dickson (1959) that in cases of special interest, e.g. cod and haddock, s_0 is a measurable quantity. Thus α for these fish must always lie between the limits given in (3.14).

4 THE COMPONENT PARTS OF THE CATCH DERIVED FROM VARIOUS REACTIONS OF FISH TO FEATURES OF BOTTOM TRAWL GEAR GEOMETRIES

4.1 Introduction

The mechanisms by means of which a fish could detect the arrival of a fishing gear in its vicinity have been discussed in section 2. While a fish may react to the presence of other fish as well as to fishing gear, it is likely that fish interaction will not be significant in many cases of interest, i.e. non-shoaling fish, unless the fish density is at a very high value. This suggests that the density in the natural environment would not be maintained at such a high value, and that an increase in density would only come about by some external influence, for example, a fishing gear which concentrates the fish in the net mouth by the shepherding action of bridles and boards. However, the equations which follow have been left in general terms for behaviour in the net mouth, and the assumption of zero fish interaction has only been made for those fish in the path of the bridles or boards; in other words, those fish in regions of relatively low density. These fish can therefore be considered as individuals, and the final catch considered as a sum of non-interacting components, which are derived from fish which have different original positions relative to the gear. The four components dealt with below are shown diagrammatically in figure (4.1).

The catching power of the gear on one side only of the centreline has been included in the following equations. The gear is assumed to be symmetrical with respect to this line ($y = 0$) and so the actual catch will be twice that indicated below.

While the movement of fish in 2 dimensions only is considered in this section, the more general problem in 3 dimensions is discussed in Appendix C. It is shown there that the following equations can be adapted to take account of vertical fish movement provided that this is small compared with the horizontal component.

4.2 Fish in the direct path of the net mouth

The formula in this case is elementary. Catches are all referred to unit fishing time, and so

$$C_1 = p V_T Y_N \quad (4.1)$$

p is assumed constant, and is the average number of fish in the sieved water column of interest, per unit area of the sea bed.

4.3 Fish in the direct path of a bridle, but not within the range of board influence

Consider a fish originally at a point $y = y'$. The fish is assumed to react to a bridle, when the latter is a distance R_g from it, by swimming in a direction normal to the bridle for a distance s and then stopping. While the angle between a bridle and the direction of motion of a reacting fish is probably variable over a wide range, the basic assumption here is that the mean direction is normal to the bridle, and so the following equations can be taken as averaged over a number of fish. The validity of this argument will depend on the number of fish in the catch component being sufficiently large.

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The probability that a fish at point y , which is distance R_B from a bridle, will react so that it does not escape is ϵ_s . This factor depends on y through

$$\epsilon_s = \epsilon_{s0} + \beta(y - y_N) \quad (4.2)$$

The change in y -coordinate per reaction is $-s \cos \theta$, and so the number of fish per unit time shepherded into the area $y > y_N$ is

$$C_2 = \int_{y_N}^{y_B - R_B} \rho V_T \exp \left[\int_{y_N}^{y'} \log \epsilon_s \cdot \frac{dy}{s \cos \theta} \right] dy' \quad (4.3)$$

R_B is the board reaction distance, and the integral limit $y_B - R_B$ is determined by the definition of the fish included in this catch component.

Equation (4.3) is quite general, and allows for an arbitrary variation of ρ , ϵ_s and s with y or other variables. To proceed further it is necessary to specify these parameters in more detail. Take ρ and s as constants, and let ϵ_s be defined by (4.2) with β a constant which is small. This last statement enables all but first order terms in β to be ignored, and so (4.3) reduces to

$$C_2 = \rho V_T \int_{y_N}^{y_B - R_B} \epsilon_{s0}^{\frac{y - y_N}{s \cos \theta}} \left[1 + \frac{\beta}{2 \epsilon_{s0}} \cdot \left(\frac{y - y_N}{s \cos \theta} \right)^2 \right] dy \quad (4.4)$$

and by integrating out

$$C_2 = \frac{\rho V_T s \cos \theta}{\log \epsilon_{s0}} \left[(\epsilon_{s0}^{N_2} - 1) \right. \\ \left. \frac{\beta s \cos \theta}{2 \epsilon_{s0} (\log \epsilon_{s0})^2} \left\{ \epsilon_{s0}^{N_2} \left[2 - 2 N_2 \log \epsilon_{s0} + N_2^2 (\log \epsilon_{s0})^2 \right] - 2 \right\} \right] \quad (4.5)$$

$$\text{where } N_2 = (y_B - R_B - y_N) / s \cos \theta \quad (4.6)$$

(4.5) and (4.6) give the final equation. Its significance can be seen by taking the limiting case, $\beta \rightarrow 0$ and $\epsilon_{s0} \rightarrow 1$ (i.e. 100 percent bridle shepherding efficiency).

Then

$$C_{2,1} = \rho V_T s \cos \theta N_2 \\ = \rho V_T (y_B - R_B - y_N) \quad (4.7)$$

This is the expected result. It is further noted that C_2 is always less than $C_{2,1}$ for $0 < \epsilon_{s0} < 1$.

4.4 Fish which are affected by the boards

Fish originally at a point y' for which $y_B - R_B < y' < y_B$ are liable to be affected by the boards, probability ϵ_B . It is assumed that those fish will react so that they move into a narrow range of y values around $y_B - R_B$. After a short time they will come within range of the bridle, and a fraction will be shepherded into the net mouth. The number of fish per unit time affected by the board is $\rho V_T R_B \epsilon_B$, and the principles of the previous section can then be applied to give

$$C_3 = \rho V_T R_B \epsilon_{so}^{N_2} \epsilon_B \left(1 - \beta \frac{N_2^2 s \cos \theta}{2 \epsilon_{so}}\right) \quad (4.8)$$

Again the limiting case, with $\beta \rightarrow 0$ and $\epsilon_{so} \rightarrow 1$ is

$$C_{3,1} = \rho V_T R_B \epsilon_B \quad (4.9)$$

4.5 Fish which come within range of the boards, but are not affected by them

The reason for subdividing fish in the region $y_B - R_B \leq y' \leq y_B$, is that the fraction $(1 - \epsilon_B)$ which are not influenced by the board disturbance may still be shepherded by the bridle connecting that board to the net. Having selected this particular group for study in this section, it is not valid in the general case to assume that they will behave towards the bridle in the same way as the proportion ϵ_B which did respond to the board. In other words whatever factor causes a reaction to a board may also be related to the strength of the response to a bridle. This is taken account of by introducing the parameter ϵ_{BB} , which is defined by the statement that the potential catch per fish in the former group is reduced in proportion to $(1 - \epsilon_{BB})$ relative to that for fish affected by the board.

The equation for this catch component can now be formulated, giving

$$C_3' = \frac{C_3(1 - \epsilon_B)(1 - \epsilon_{BB})}{\rho V_T R_B \epsilon_B} \int_{y_B - R_B}^{y_B} \rho V_T \epsilon_{so}^{\frac{y - y_B - R_B}{s \cos \theta}} \left[1 + \frac{\beta}{2 \epsilon_{so}} \left(\frac{y - y_B - R_B}{s \cos \theta}\right)^2\right] dy \quad (4.10)$$

which is evaluated to

$$C_3' = \frac{\rho V_T s \cos \theta (1 - \epsilon_B)(1 - \epsilon_{BB})}{\log \epsilon_{so}} \epsilon_{so}^{N_2} (\epsilon_{so}^{N_3} - 1) \left[1 - \frac{\beta s \cos \theta}{2 \epsilon_{so}} \left\{N_2^2 + \frac{\epsilon_{so}^{N_3} [2 - 2 N_3 \log \epsilon_{so} + N_3^2 (\log \epsilon_{so})^2] - 2}{(\log \epsilon_{so})^2 (\epsilon_{so}^{N_3} - 1)}\right\}\right] \quad (4.11)$$

where $N_3 = R_B/s \cos \theta$

The limit of expression (4.11) for $\beta \rightarrow 0$, $\epsilon_{so} \rightarrow 1$, $\epsilon_{BB} \rightarrow 0$ is

$$C_{3,1}' = \rho V_T R_B (1 - \epsilon_B) \quad (4.12)$$

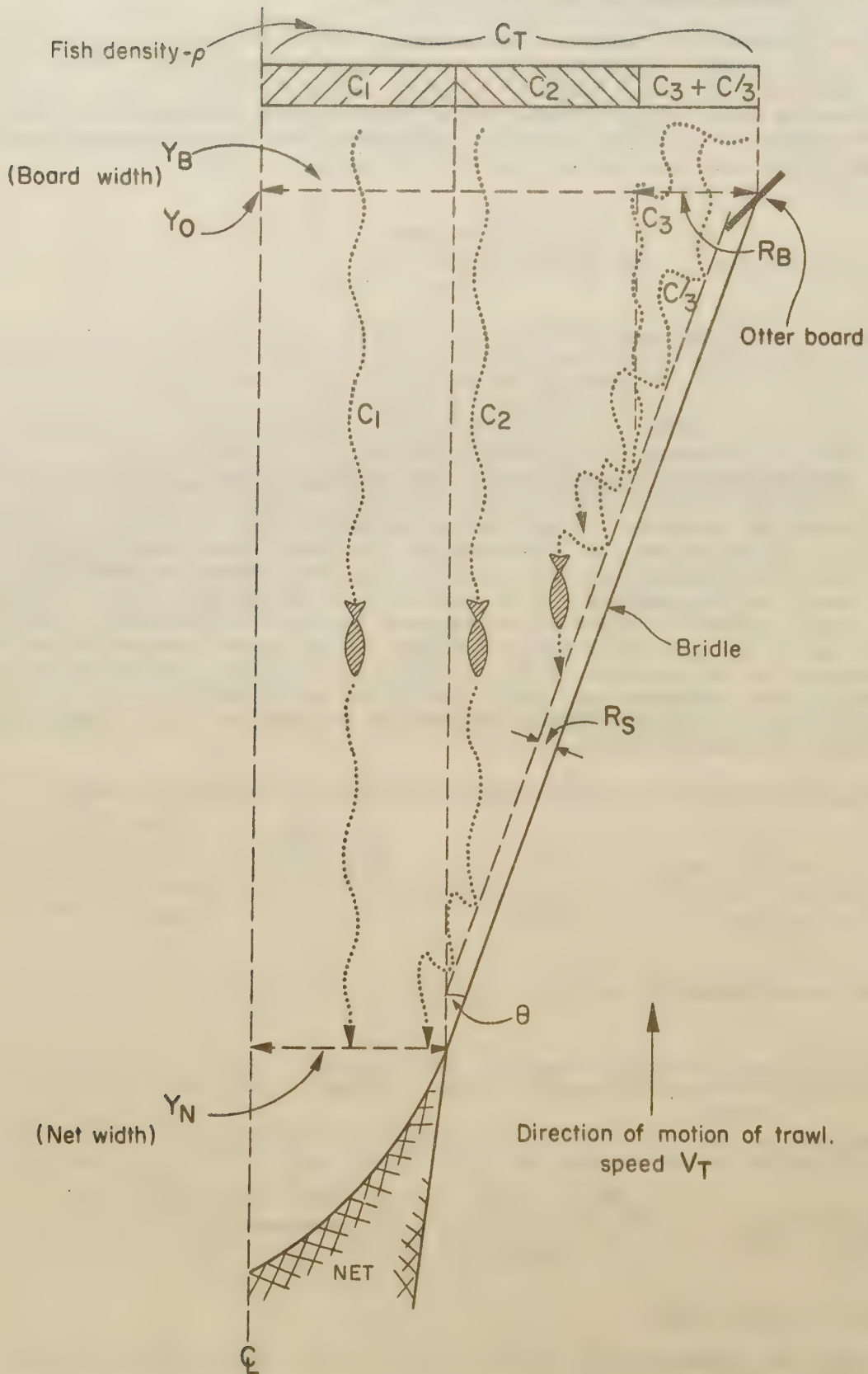


Fig. 4(1) Alternative paths of fish relative to the trawl gear when influenced by different components of the gear

4.6 Overall yield

Once the catch components described in sections (4.2) - (4.5) have arrived in the region of the net mouth, it remains to combine them into an expression for the overall yield, i.e. number of fish which get into the codend, per unit time. The fish may still have a chance of escape, and as mentioned previously, this may partly arise from the high densities which might be expected in this area.

As the fish in the different catch components have had different histories, they cannot be assumed to have the same chance of escape once in the net mouth. The yield is therefore described by the equation

$$Y = \epsilon_{g1} C_1 + \epsilon_{g2} C_2 + \epsilon_{g3} C_3 + \epsilon'_{g3} C'_3 \quad (4.13)$$

where ϵ_{gr} is the proportion of C_r which gets into the codend.

Where fish interaction in the net mouth is important, the ϵ_{gr} will of course be a function of all the catch components, and would only be regarded as constant multipliers in the limiting case $C_r \rightarrow 0$. In addition to such an effect, the capacity of the fish for the effort required to make an escape (where this is done by swimming faster than V_T) will be related to the ϵ_{gr} . While the detailed effect of basic fish behaviour dynamics on the various parameters in equation (4.13) is considered elsewhere in this paper, it may be mentioned here that the ϵ_{gr} would be expected to increase with the total distance swum. That is to say

$$\epsilon_{g1} < \epsilon_{g2} < \epsilon_{g3} < \epsilon'_{g3} \quad (4.14)$$

and, of course, $\epsilon'_{g3} \leq 1$.

5 RELATIONSHIP OF FISH BEHAVIOUR EQUATIONS TO OVERALL YIELD IN TRAWLING OPERATIONS

5.1 Introduction

The equations derived in section 3 will now be applied to fish in the vicinity of a trawl gear. The general assumption about fish response to the stimuli provided by shepherding devices have already been discussed in sections 2 and 4.

One of the important factors dealt with in section 3 was fish endurance, as defined by s_e and t_e . Clearly fish which become exhausted before they are shepherded into the path of the net will be lost, and therefore endurance can be thought of as a factor to be included in any derived expression for the various ϵ 's. However, it is not possible to say at the present time that the ϵ 's are dependent only on endurance, but certainly any ϵ can be considered to be composed of "normal" and "endurance" terms, written as ϵ_n and ϵ_e respectively. ϵ_n will be determined by such factors as the ability of a fish to perceive a stimulus, and any conditioning which may occur when stimuli are repeated over a period.

The following equations are only concerned with ϵ_e , which can be defined by

$$\epsilon_e = \epsilon, \text{ when } \epsilon_n = 1 \quad (5.1)$$

It is obvious that the effect of endurance will depend on the distance a fish has to swim over the period when it is being shepherded by a particular device. This distance is greatest in the case of a bridle, which is therefore selected for the most detailed consideration in this section. Other effects, such as those due to boards will be treated as a boundary condition to the bridle problem.

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5.2 Endurance equations related to bridle stimulus

When it reacts to the presence of a bridle, a fish moves a distance s . The component of trawl velocity in the assumed direction of fish motion is $V_T \sin \theta$, and so we get

$$m = \frac{V_T \sin \theta}{V} \quad (5.2)$$

The fish first reacts to the bridle at $t = 0$. At this point, let $E = E_1$ and $V = V_1$. Equation (3.8) can now be solved to give

$$V(t) = V_c \frac{\frac{V_1 + V_c}{V_1 - V_c} \exp(2 \sin \theta \propto b V_c V_T t) + 1}{\frac{V_1 + V_c}{V_1 - V_c} \exp(2 \sin \theta \propto V_c V_T t) - 1} \quad (5.3)$$

also, from equation (3.2)

$$E_1 - E(t) = \frac{1}{\propto} [V_1 - V(t)] \quad (5.4)$$

and

$$s(t) = \int_0^t V(t) dt$$

$$= \frac{V_c}{\sin \theta \propto b V_c V_T} \log \left[\frac{(V_1 + V_c) \exp(2 \sin \theta \propto V_c V_T t) - (V_1 - V_c)}{2 V_c \exp(\sin \theta \propto V_c V_T t)} \right] \quad (5.5)$$

The final equation required, to give V_1 , is

$$V_1 = V_M - \propto (E_n - E_1) \quad (5.6)$$

and now, putting $t = t_e$ and $E(t) = E_o$, $V(t)$, V_1 and t_e can be eliminated between equations (5.3-6) to arrive at the functional dependence of s_e on E_1 . As the form of the resultant equation is rather complex, write

$$E_1 = F_1(s_e) \quad (5.7)$$

Fish which react to the bridle at point y' will not all have the same value of E_1 . The range of values encountered will in fact be determined by the history of the fish in the period $t < 0$, not only for the period before the trawl operation but also arising from the reaction of the fish to the boards, where applicable. Let $N(E_1) \Delta E$, be the number of fish per unit time which encounter the bridle, for the first time, and which have a value of E , lying between E_1 and $E_1 + \Delta E_1$. $N(E_1)$ may be a function of y' , and this relationship will also be determined by the previous history of the fish.

If y_e is the y -coordinate of a fish at the point of exhaustion, then

$$s_e = \frac{y' - y_e}{\cos \theta}$$

Thus a fish which has $E = E_1$ at $t = 0$ will escape over the bridle at or near $y = y_e$. Now the total number of fish which have not escaped in the region between y' and y_e is

$$\int_{E_1}^{E_n} N(E) dE \quad (5.9)$$

Of course, because of our assumption that a fish swims a non-zero distance away from a source of stimuli, those fish included in expression (5.9) will not react with the bridle exactly at point y_e , but will do so over a range of y given by

$$y_e - s \cos \theta \leq y \leq y_e \quad (5.10)$$

Hence the number which escape in this region is given approximately by

$$N(E_1) \frac{\partial E_1}{\partial y_e} s \cos \theta \quad (5.11)$$

and so, by definition

$$\epsilon_{se}(y_e, y') = \frac{N(E_1) \frac{\partial E_1}{\partial y_e} s \cos \theta}{\int_{E_1}^{E_n} N(E) dE} \quad (5.12)$$

(5.12) gives ϵ_{se} as a function of y_e and y' . If ϵ_{se} is not strongly dependent on y_e , as was assumed in section 4, we can write

$$\epsilon_{se}(y_e, y') = \epsilon_{soe}(y') + \beta_e(y_e - y') \quad (5.13)$$

where β_e is the component of β arising from fish endurance effects. ϵ_{soe} is similarly related to ϵ_{so} . Hence, given the form of $N(E)$, expressions for β_e and ϵ_{soe} can be derived by comparing (5.13) with (5.12), having expanded the latter and retained only first order terms in y_e .

5.3 Endurance related to the chance of escape of a fish which has arrived in front of the net mouth

The behaviour of fish in the immediate area of the net has previously been considered only in general terms. This is because the parameters $\{\epsilon_{g1} \dots \epsilon_{g3}\}$ could be dependent of fish interaction. However, even if the fish has an increased chance of escape, by outpacing the trawl, because the density of fish in the net mouth is high, its endurance will still determine its capability to do so. This is especially the case if the trawl velocity is greater than the cruising speed of the fish.

The "energy spectrum" of fish in the net mouth which are included in catch components C_2 , C_3 and C_4 will depend on their previous history as defined by equations (5.1-7). In the case of fish in component C_1 , which have been assumed not to interact with parts of the gear other than the net, the spectrum will be that of fish in the natural state, i.e. those removed from the area of trawl operation. However, the spectrum of the other components will be modified from the natural state by the exertion

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of the fish which have responded to the soaring effects of bridles and boards. Now the chance of fish escaping by swimming forward once it is in front of the net mouth would be expected to increase with the time for which it is capable of keeping up with the trawl, if $V_T > V_0$. Once the fish is exhausted, of course, it would fall back into the net. This time will depend on the value of E for the fish in question, when it crosses the point $y = y_N$. This will in turn be dependent, among other things, on the distance it has swum since first coming in contact with the gear. This reasoning, when applied to the yield equation, leads to equation (4.14).

5.4 The functional dependence of the behaviour and yield parameters

A large number of parameters have been incorporated in the analysis presented in sections (3-5). These have generally been defined in terms of their physical significance so that it would be clear what kind of experimental work would be necessary to derive values for substitution in the equations. However, for a proper understanding of the meaning of these equations, it is also necessary to consider the interrelationship of these parameters, that is, their functional dependence. In many cases this has been determined by the assumptions which have been stated and used in the analysis. In addition, for the purpose of obtaining practical results from the equations it is necessary to reduce their complexity by making certain approximations to the rigorous case. In other words, weak functional dependence may be neglected in favour of the stronger relationships in a particular equation.

6 CONCLUSIONS

The equations that have been formulated for the 2-dimensional case should provide a basis by means of which the results of experiments can be used for the prediction of catching capability of different designs of trawls and trawl rigging. The hypotheses that have been put forward have been kept general but in the derivation of many of the equations simplifying assumptions have been made which do not cover certain cases, especially for midwater fishing and for the capture of pelagic and shoaling species in general. In the light of the limited experimental data available, including some comparative fishing results, some first approximations of the main parameters which affect the catching performance have been estimated. These estimates have allowed numerical solutions of the equations to be obtained which demonstrate the sensitivity of catching performance to some of the parameters, in particular, the ϵ values.

Had a more complete set of background information been available, a more accurate approach to the determination of ϵ_g would have been to relate other unknowns in the general equations to the results of laboratory experiments, hence indirectly deriving quantitative information on the escape probability. It is to be hoped that in the future it will be possible to correlate data from properly designed experiments, to the results of chemical and biochemical analysis of the muscles, and associated features, which determine the endurance of the fish.

Laboratory studies of the swimming speeds of fish should be specially directed to distinguishing between true burst speed, cruising speed and endurance in both cases. If there is not a clearly defined boundary then much more information on the fall off of speed with time should be recorded. For practical application it is essential that commercial species like cod, haddock and the flatfish should be used despite the inherent difficulties of obtaining representative samples.

Detailed hydrodynamic measurements on complete nets suggest that a relatively small but perhaps important pressure field is built up in the front of nets and that to ensure that this value is kept as small as possible, nets with low taper not exceeding about 10° should be used. The effect of this hydrodynamic pressure is incorporated in the equations since the C_g figures can be defined to include this effect together with other escape reactions that the fish may show through the noise of the trawl together with any tendency of the fish to resist the close herding together that precedes capture.

Direct quantitative measurement of the ϵ values will inevitably be difficult to achieve even with the use of underwater submarines, towed vehicles, etc. but it is not difficult to visualize experiments which would provide answers to within an acceptable accuracy. This work should be strongly backed up with comparative fishing tests where the effects of different configurations should be tested over wide variations initially, and once the slopes of the curves of catching efficiency against the parameters have been deduced, areas of special interest should then be studied in detail.

Much of the experimental information used in the numerical evaluation of the equations is derived from unpublished information which is currently being obtained in a long series of comparative fishing experiments being jointly undertaken by the laboratories at Aberdeen and Lowestoft.

For highest efficiency according to present results trawl gear should be designed along the following lines:-

- (a) The net should be of slow taper (not exceeding about 9°). It is clear from the study of many commercial fishing operations that catch rates are seriously influenced by the temporary removal of the groundrope from the seabed during the tow as a result of variations in the bottom contours, and this is especially true when higher headline gears are used. The groundrope should be weighted throughout its length to an extent larger than is currently commercial practice so that in the towing condition at all speeds there is an overall excess of potential down weight from the groundrope of not less than 6-700 lbs. Where high headline gears are considered necessary this figure should be increased by a factor of 2.
- (b) Bridle lengths should be as long as practically acceptable. The angle of the bridle to the direction of motion should not exceed about 20° and for flatfish angles of 4 or 5° less than this should be used. These limitations on bridle length and angle automatically involve high board spreads and relatively high spreading efficiency of the boards.

Information to date suggests that good hydrodynamic efficiency rather than large size is the most satisfactory method of obtaining the necessary spreading power but this must depend on what proportions of the board influence are due to noise and hydrodynamic pressure. For some species the movement may be horizontal and hence the fish are directed into the path of the bridles and nets but for others a large proportion may be scared vertically as well as horizontally to such an extent that there is a high proportion of fish not within the catching zone. The relevant general theory is given in Appendix C.

The derived equations for optimising trawl speed have not been presented, since they are so much dependent on the fish behaviour parameters. Some approximate derivations have been made using the values of the parameters suggested here and they suggest that speeds of a little above 4 knots should be used for the demersal fish considered. This might involve a slight drop in the proportion of smaller fish caught. A similar effect would be obtained by the use of very large bridle angles.

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7 LIST OF PRINCIPAL SYMBOLS

a	Vertical movement of a fish reacting to a bridle.
b	Factor related to the hydrodynamic drag and swimming efficiency of a fish.
C_1	The catch component arising from fish initially in the path of the net mouth.
C_2	The catch component arising from fish in the path of a bridle, but which are not influenced by the boards.
$C_{2,1}$	Value of C_2 for zero escape.
C_3	The catch component arising from fish which are influenced by the boards.
$C_{3,1}$	Value of C_3 for zero escape.
C'_3	The catch component arising from fish which are not influenced by the boards, although passing within the range of board influence.
$C'_{3,1}$	Value of C'_3 for zero escape.
$E, E(t)$	Energy factor at time t .
E_n	"Normal" value of $E(t)$.
E_0	Value of $E(t)$ at the point of exhaustion.
E_1	Value of E for a particular fish when it first encounters a bridle.
h	Mean headline height.
l	Length of a fish.
m	Proportion of the time for which the fish velocity is non-zero.
$n, n(y,z)$	Number of times a given fish starting from (y,z) interacts with a bridle.
N_2	Number of bridle interactions between $y_B - R_B$ and y_N .
N_3	Number of bridle interactions between y_B and $y_B - R_B$.
$N(E)$	Number of fish which have an energy factor = E , per unit range of energy factor.
p	Factor related to the power production capacity of a fish.
P	A critical value of y , above which no fish are caught.
R_B	A fish has to approach a board to within this distance in order to have a chance of reacting to it.
R_S	A fish has to approach a bridle to within this distance in order to have a chance of reacting to it.
$s, s(t)$	Distance a fish swims when it is stimulated or scared at time t .
s_e	Total distance swum from a defined starting point until the fish is exhausted.

t	Time variable.
t_e	Time taken to cover the distance s_e .
t_n	The most recent time which satisfies $E(t_n) = E_n$.
$V, V(t)$	Speed of a fish immediately following a stimulus at time t .
V_C	Cruising speed.
V_M	Maximum speed, i.e. speed of a fully rested fish following the application of a strong stimulus.
V_T	Speed of the trawl.
x, x'	Point coordinates referred to an axis parallel to the direction of motion of the trawl.
y, y'	Point coordinates referred to a horizontal axis perpendicular to the direction of motion of the trawl.
y_B	y -coordinate of an otter board
y_e	Value of y at which a fish is exhausted.
y_N	y -coordinate of a wing end.
Y	Overall yield per unit time.
z, z'	Point coordinates referred to a vertical axis.
z_m	Maximum height above the sea bed. There are no fish of interest at points $z > z_m$.
$Z, Z(y)$	Critical height. Fish at points $z > Z$ will not be caught.
α	Variation of V per unit change of energy factor.
α_C	Critical value of α .
β	Change in ϵ_p per unit change in y .
β_e	The component of β which is determined by fish endurance considerations.
γ	The power of V which is proportional to the thrust generated by a fish swimming at speed V .
ϵ_B	The proportion of fish in the path of the board influence area which react to the board so that the y -coordinate of the fish changes to a value $< y_B - R_B$.
ϵ_{BB}	The proportion of fish in the path of the board influence area which are not affected by the board, and are also not affected by the bridle for reasons other than those associated with the factor ϵ_s .
$\epsilon_s, \epsilon_s(y)$	The proportion of fish in the path of a bridle which, when approached by the bridle to a distance R_s , move so that they do not escape over the bridle.
$\epsilon_{se}(y_e, y')$	The component of ϵ_s which is determined by fish endurance considerations.

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- ϵ_{so} The proportion of fish which do not escape over a bridge the first time they are approached to a distance R_g .
- $\epsilon_{soe}(y')$ The component of ϵ_{so} which is determined by fish endurance considerations.
- ϵ_{g1} The proportion of fish in C_1 which are collected by the codend.
- ϵ_{g2} The proportion of fish in C_2 which are collected by the codend.
- ϵ_{g3} The proportion of fish in C_3 which are collected by the codend.
- ϵ'_{g3} The proportion of fish in C'_3 which are collected by the codend.
- θ Angle between a bridge and the direction of motion.
- $p(x,y,z)$ Number of fish per unit volume at the point (x, y, z) . $p(x,y,z)$ is taken to refer to a time before the fish have become aware of the trawling operation.
- $p(y,z)$ Number of fish per unit volume, averaged over all values of x covered by one trawling operation.
- $p(y)$ Number of specified fish per unit volume, averaged over all values of x , and all values of z between 0 and z_m .
- p_b Number of specified fish per unit volume at $z = 0$.
- p Number of fish per unit volume or per unit area of sea bed (see text).

8 REFERENCES

- Arlotte, T., Model flow observations on the disturbance with bottom running otter
1964 boards. Westland Aircraft Ltd., Report (H/O/188)
- Bainbridge, R., The speed of swimming of fish as related to size and to the frequency
1958 and amplitude of the tail beat. J.exp.Biol., 35(1):109-33
- _____, Speed and stamina in three fish. J.exp.Biol., 37(1):129-53
1960
- _____, Problems of fish locomotion. Symp.zool.Soc.Lond., (5):13-32
1961
- Bainbridge, R. and R.H.J. Brown, An apparatus for the study of the locomotion of fish.
1958 J.exp.Biol., 35(1):134-7
- Bainbridge, R. and T.H. Waterman, Turbidity and the polarized light orientation of the
1958 crustacean mysidium. J.exp.Biol., 35(3):487-93
- Blaxter, J.H.S. and W. Dickson, Observations on the swimming speeds of fish. J.Cons.
1959 perm.int.Explor.Mer., 24(3):472-9
- Blaxter, J.H.S. and B.B. Parrish, The reaction of marine fish to moving netting and
1966 other devices in tanks. Mar.Res., 1966(1):1-15
- Boddeke, R., E.J. Slijper and A. Van Der Stelt, Histological characteristics of the
1959 body-musculature of fishes in connection with their mode of life. Proc.
K.ned.Akad.Wet.(C), 62(5):576-88
- Chestnoi, V.N., On optimum trawling speeds. Ryb.Khoz., 37(7):43-9
1961

- Crewe, P., Estimates of bottom trawl gear catching performance. Westland Aircraft
1965 Ltd., Report (H/O/176)
- Enger, P.S., Acoustic threshold in goldfish and its relation to the sound source
1966 distance. Comp.Biochem.Physiol., 18(4):859-68
- Foster, J.J., A report of experiments with the French trawl gear - fully instrumented
1964 tests and comparative fishing. In Report 4th I.F. meeting, Hamburg,
Oct. 1964
- Gulland, J.A., Statistical aspects of comparative fishing trials. Rep.FAO/UNDP(TA),
1967 (2277-II):349-54
- Lighthill, M.J., Note on the swimming of slender fish. J.Fluid Mech., 9:305-17
1960
- Magnan, A., Les caractéristiques géométriques et physiques des Poissons. Ann.Sci.
1930 nat.(b), 13:355
- McCauley, R.W., Thermal relations of geographic races of Salvelinus. Can.J.Zool.,
1958 36:655-62
- Mohr, H., Zum Verhalten von Fischeschwärmen beim Fang mit pelagischen Schleppnetzen.
1963 (The behaviour of fish shoals during the catch by means of pelagic trawl.
Protok.FischTech. 8(37):149-59
- Nursall, J.R., The lateral musculature and the swimming of fish. Proc.zool.Soc.Lond.,
1956 126(1):127-43
- _____, A method of analysis of the swimming of fish. Copeia, 1958(2):136-41
1958
- _____, Swimming and the origin of paired appendages. Am.Zoologist, 2:127-41
1962
- Reece, J.W. and J. Siekmann, Swimming of flexible hydrofoil near a free surface.
1964 Z.angew.Math.Mech., 44(12)
- Reece, J.W., J.P. Uldrick and J. Siekmann, Some recent developments in the sea.
1964 Animal locomotion hydrodynamics. In Developments in theoretical and
applied mechanics. Southeastern Conference on Theoretical and Applied
Physics, edited by W.A. Shaw. New York, Pergamon Press, vol.2:337-49
- Rosen, M.W., Experiments with swimming fish and dolphins. Pap.Am.Soc.mech.Engrs,
1962 (61-WA-203)
- Schärfe, J., Observations with echo-sounding on the behaviour of a herring shoal
1955 towards a bottom trawl. ICES Comparative Fishing Committee, C.M. 1955
(42):
- Schiemanz, F., Das Schwimmen der Fische in Fischtreppe und die günstigste Gestalt
1959 der Durchlässe und Becken in den Fischtreppe. Z.Fisch., 8(1-3):199-220

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Acknowledgments

The author wishes to acknowledge the many references and papers, all of which have not been specified. These have been used to devise plausible assumptions for the solution of numerical cases in the various equations.

Special thanks are due to Mr. D.N. MacLennan for his continued help and advice throughout the preparation of this paper.

APPENDIX ASome comparative fishing results - Bottom trawl gear optimisation

1 BACKGROUND

The comparative fishing results discussed in this appendix arose because of the disappointing results of comparative fishing experiments between a newly developed high headline, wide-opening trawl and a standard Granton trawl. The increased geometrical values between the Granton trawl and the developed trawl were as follows: opening height of the net was increased from 6 ft to 14 ft, and the net mouth width was increased from approximately 45 ft to 60 ft, and the increase in otter board spread was from 190 ft to approximately 220 ft. The enormous increase in the volume of water sieved, and the considerable increase in the area on the sea bed covered, were understandably expected to provide a substantial increase in catch. The two comparative fishing trips in the Barents Sea area during the winter months of 1963, suggested that there was no significant difference between the catching rates of the two trawls.

As in many comparative fishing experiments the results were not completely convincing; statistically it was still possible that the larger gear had had a fishing capacity, of order 20 to 30 percent, better than the standard. This is, however, not true if the two experiments are combined together, and in any case, even if a small difference between the gears did exist, it was still not in the same order of magnitude of the improvement desired.

This clear demonstration of the importance of fish behaviour in relation to catching power, in addition to the importance of the engineering parameters in gear design with wide coverage or large sieving capacity, led to the undertaking of a large series of comparative fishing experiments which were designed to isolate the parameters of trawl gear which influence the catch.

2 OBJECTIVES

It was suggested that the scheme should be formulated in such a way that the effects of individual parameters like board spread, bridle length, etc. should be studied one at a time. Many authors, describing comparative fishing techniques, postulate the need for such an approach, but in practice it is just not possible to isolate the parameters and vary one alone. The parameters themselves are so much interrelated that it is difficult to think of any one which can be varied without varying one or more others. For example, a change in speed, or distance covered by the trawl from one gear to the other, necessarily means that a different area of ground is fished, and it is unlikely that the density of the fish remains identically the same over wide areas. Furthermore, a change in speed must be accompanied by a change in the drag of the net and the consequential change in the force applied to the otter boards, which in turn alter the spread of the gear. The latter problem can be solved by changing the spreading force of the otter board or the net construction to suit the different speeds, but again the scaring or shepherding effect of the otter boards and/or the pressure fields and other stimuli will be altered.

Where speeds of the two gears being compared are kept the same, the situation is a little better, but changes in bridle length, for example, automatically involve changes in the spread of the boards unless the size of the board is reduced to keep the same spread. This again may alter the catch because of the change in scaring or herding effect of the board due to its physical size or its associated hydrodynamic pressure field which is built up as it is towed through the water.

On the basis of the limited knowledge of the behavioural characteristics discussed in section 2, it was decided that the effect of speed could be partly covered by its interrelated influence with bridle angle, and should be kept aside until the major in-

fluences of the geometrical parameters were more clearly understood. Three examples of the types of comparisons chosen and still under investigation are:-

- (a) The combined effect of changing the spread of the otter boards and the length of the bridles at a fixed net spread and bridle angle.
- (b) The combined effect of changing bridle angle and board spread at a fixed bridle length and net spread.
- (c) The effect of changes in net width and bridle angle at fixed board spread.

Very broadly, the most statistically significant result so far obtained, was that changes in sweep length associated with changes in board spread provided catches which change proportionately according to the lengths of the bridles. This result was fully expected, since it has long been known by practical fishermen that bridles should be as long as possible, limited mainly by the chance of damage expectancy.

Other results of the cruises are noted in the following summary but precise details of the experiments are not given since they are reported in detail by (Bridger, this conference).

3 BRIEF SUMMARY OF RELEVANT COMPARATIVE FISHING EXPERIMENTS

The first commercial comparative fishing trip (January/February 1963) was a comparison between a Saunders-Roe type high headline, wide-opening gear and a standard Granton trawl. Some comparison between the Granton trawl and a low spread, high-opening trawl were also made.

	Granton trawl	High- and wide-opening SARO trawl (L)	Low spread, high-opening SARO trawl (S)
Board spread (ft)	186	214	147
Maximum net height (ft)	6	14	16
Net width (ft)	50	60	(50)
Catch ratio* (cod and haddock)	1.27	145	1

The bridle lengths and trawl speeds were 240 ft and 3.5 knots respectively.

*The ratios $G/SARO (S)$ and $SARO (L)/G$ are not significantly different from unity at the 95 percent probability level.

The second commercial comparative fishing trip (March 1963) testing virtually the same gears under similar conditions, provided answers not substantially different from the first test above.

The third commercial comparative fishing trip (January/February 1964) compared the catching rates of a standard Granton trawl with 40 fathom bridles, with bridle angles to the direction of motion of 17, 14 and 11 degrees. The otter board spreads corresponding to the three angles were in the ratios 183 : 169 : 135. The catching ratios between these gears were not significantly different from unity but there is a slight indication that at the very small angle the catch rate falls. It can be concluded that the reduction in total area fished is compensated by the increase in effectiveness of the small bridle angle.

The fourth comparative fishing trip (March/April 1964) was designed to examine the effect of bridle length at fixed bridle angle and board spread.

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Bridle length (fm)	17½	40	70
Otter board spread ratio	1	1.75	2.54
Catch ratio	1	1.7	2.54

It should be noted that the bridle angles obtained in practice were not quite equal and the bridle lengths 17½, 40 and 70 fms corresponded to values of approximately 20, 18½ and 18 degrees, respectively. Within the 95 percent confidence limits, using various statistical analyses ignoring hauls where slight damage or other possibilities of invalidating the haul occur, gives the following comparisons:

70/40	1.5 ± 0.27
17½/40	0.59 ± 0.10

In the fifth comparative fishing trip (February/March 1964) an attempt was made to compare the use of large otter board spreads with fixed net spread and bridle length on Granton trawls. This experiment necessitated the use of restricting wires across the opening of the net when the large angles and board spreads are used.

Very few results were obtained and in any case the experiment is suspect since the vibration from the truss rope may seriously affect the catching efficiency of the net itself. The sudden change in angle between the wing-end part of the groundrope and the bridle may also be important. Board spreads of order 320 ft corresponding to bridle angles of approximately 32 degrees and 215 ft corresponding to 19 degrees were obtained. This experiment must be considered to suggest no more than a vague hint that bridle angles exceeding 30 degrees are inefficient.

It should also be pointed out that the large spreads and angles were attained by the use of large, efficient, cambered types of otter boards.

The sixth comparative fishing test (April 1964) provided a further series from the fifth, but the results are extremely confused owing to an enormous, unexplained ship difference between the ships used, i.e. "Explorer" and "Ernest Holt". The statistical analysis gives such wide variations at the 95 percent confidence limit that they are best ignored.

The seventh comparative fishing trip (February/March 1965) was designed to compare the use of two bridle lengths, 60 and 40 fm, at fixed otter board spread on the Granton trawl. Two separate areas were used for the test (Faroe and S.E. Iceland), and whilst some short sets of compared hauls indicated differences, especially in flatfishes, the comparison 60/40 bridle lengths are not significantly different from unity at the 95 percent confidence limit.

The eighth comparative fishing trip (July 1965) was designed to compare the catching performance of the high- and wide-opening SARO trawls at fixed otter board spread with different bridle lengths. Extension of the wing-ends was used to maintain the same net spread for the two alternatives. Three main areas for the test were used: S.E. Iceland, S.W. Iceland and Faroe. The general impression gained was that for flatfish a large difference occurs, measured at 62/40 equivalent to an increase of 2.3 : 1 and for cod a ratio of 1.7 and significantly different from unity, at 95 percent confidence limits. The results for haddock are not significantly different from unity, but the ratios are in the same direction as for the other species.

The ninth comparative fishing trip (November 1966) was designed to repeat the comparisons of the eighth trip in the Norwegian/Russian coast area in winter conditions, since the results for the large gear had not been consistent with those of the standard Granton gear. Again the ratio 62 : 40 in bridle length produced a catch ratio significantly greater than unity at a value of about 1.25, but an enormous ship to ship difference makes the result somewhat suspect.

These later experiments suggest that the optimum value expressed in terms of rate of change of catching efficiency with increase in bridle length, occurs at a greater length for the high-opening and wide-spread nets than it does for the standard Granton trawl.

Throughout the test procedures so far, sophisticated statistical techniques have been used in setting up the test models and analysing the results of the various unknown factors (between the gears and the ships, and between the ships, etc.) have been given careful consideration. One of the remaining questions at the end of this series was the possible difference between the sides of the ship. It was suggested that slight difference in the shooting and hauling procedures and direction of tow relative to the fore and aft axis of the boat might have an influence. An individual experiment on "Explorer" (February 1967) using identical gears on the two sides of the ship using a carefully designed model for changeovers between sides, was conducted, and the results showed that there was no significant difference on that ship at that time on the particular species fished!

In view of results of these latter cruises, a direct comparison between the wide opening high headline gear and a Granton trawl with bridle length of 60 fm is to take place in November this year.

APPENDIX BEvaluation of the yield equation with particular values of the behaviour parameters

Some numerical results from computation on the yield equation, (4.13) are presented in Table I. This indicates quantitatively the way in which equation (4.13) depends on its component parameters. Results are given for various values of R_B , s , β , ϵ_{s0} , ϵ_B and ϵ_{BB} . For the other parameters one value only has been selected, but these are in the main quantities for which it is easy to derive values related to a typical bottom trawl operation. Parameters with fixed values are:

$$V_T = 7 \text{ ft/sec}, Y_B = 100 \text{ ft}, Y_N = 25 \text{ ft}, \theta = 18.2 \text{ deg},$$

$$p = 1 (\text{ft}), \epsilon_{g1} = 0.7, \epsilon_{g2} = 0.8, \epsilon_{g3} = 0.85, \epsilon_{g3}' = 0.9$$

The results show that, as would be expected, the yield drops with a decrease in s , ϵ_{s0} or ϵ_B , or with an increase in β or ϵ_{BB} . The proportional changes in Y from varying R_B over sensible limits is much less than that from ϵ_{s0} . Of course, changes in the latter would have had a greater effect had low values of ϵ_{s0} been used, but comparative fishing results (see Appendix A) suggest that this would not have been realistic.

The maximum value of β used is such that the change in ϵ_g over the length of a sweep is of the order of 10 percent. This restriction arises because of our previous assumption that only first order terms in β are important.

It will be seen that the greater part of the total yield has ended up in the net by reason of reactions to the bridles. This confirms the above statement that the chosen values of ϵ_{s0} are compatible with comparative fishing results.

TABLE I - Numerical evaluation of the yield equation

[Note: Maximum yield, 100 percent catching efficiency (Y) = 700]

Case (a) $\epsilon_B = 0.9$, $\epsilon_{BB} = 0.0$

R_B	s	β	$\epsilon_{so} = 0.9$					$\epsilon_{so} = 0.95$				
			C_1	C_2	C_3	C'_3	Y	C_1	C_2	C_3	C'_3	Y
30	5	0	175	199	70	6	347	175	250	116	11	431
		10^{-4}	175	198	68	6	344	175	248	114	11	428
		10^{-3}	175	187	53	4	321	175	233	90	8	393
	10	0	175	248	115	11	429	175	280	148	15	486
		10^{-4}	175	247	113	11	426	175	279	147	15	484
		10^{-3}	175	239	101	9	408	175	270	132	13	462
40	5	0	175	170	116	9	365	175	204	173	16	447
		10^{-4}	175	170	114	8	363	175	203	170	15	443
		10^{-3}	175	164	99	7	344	175	195	149	13	417
	10	0	175	203	171	15	444	175	223	209	21	497
		10^{-4}	175	203	170	15	443	175	223	207	21	496
		10^{-3}	175	199	159	14	429	175	218	194	19	479

Case (b) $\epsilon_B = 0.5$, $\epsilon_{BB} = 0.0$

R_B	s	β	$\epsilon_{so} = 0.9$					$\epsilon_{so} = 0.95$				
			C_1	C_2	C_3	C'_3	Y	C_1	C_2	C_3	C'_3	Y
30	5	0	175	199	39	28	340	175	250	65	55	427
		10^{-4}	175	198	38	28	338	175	248	63	54	423
		10^{-3}	175	187	30	21	316	175	233	50	41	388
	10	0	175	248	64	54	424	175	280	82	76	485
		10^{-4}	175	247	63	53	421	175	279	81	75	482
		10^{-3}	175	239	56	47	404	175	270	73	66	460
40	5	0	175	170	64	43	352	175	204	96	78	438
		10^{-4}	175	170	63	42	350	175	203	95	76	434
		10^{-3}	175	164	55	34	331	175	195	83	63	406
	10	0	175	203	95	77	435	175	223	116	104	493
		10^{-4}	175	203	94	76	433	175	223	115	103	491
		10^{-3}	175	199	88	69	419	175	218	108	94	473

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TABLE I (Cont'd)

TABLE I (Cont'd) - Evaluation of the yield equation for particular values of the behaviour parameters

[Note: Maximum yield, 100 percent catching efficiency (Y) = 700]

Case (c) $\epsilon_B = 0.9$, $\epsilon_{BB} = 0.2$

R_B	s	β	$\epsilon_{so} = 0.9$					$\epsilon_{so} = 0.95$				
			C_1	C_2	C_3	C_3'	Y	C_1	C_2	C_3	C_3'	Y
30	5	0	175	199	70	5	346	175	250	116	9	429
		10^{-4}	175	198	68	4	342	175	248	114	9	426
		10^{-3}	175	187	53	3	320	175	233	90	7	392
	10	0	175	248	115	9	427	175	280	148	12	483
		10^{-4}	175	247	113	9	424	175	279	147	12	481
		10^{-3}	175	239	101	8	407	175	270	132	11	461
40	5	0	175	170	116	7	363	175	204	173	12	444
		10^{-4}	175	170	114	7	362	175	203	170	12	440
		10^{-3}	175	164	99	6	343	175	195	149	10	414
	10	0	175	203	171	12	441	175	223	209	17	494
		10^{-4}	175	203	170	12	440	175	223	207	17	492
		10^{-3}	175	199	159	11	427	175	218	194	15	475

Case (d) $\epsilon_B = 0.5$, $\epsilon_{BB} = 0.2$

R_B	s	β	$\epsilon_{so} = 0.9$					$\epsilon_{so} = 0.95$				
			C_1	C_2	C_3	C_3'	Y	C_1	C_2	C_3	C_3'	Y
30	5	0	175	199	39	23	336	175	250	65	44	417
		10^{-4}	175	198	38	22	333	175	248	63	43	413
		10^{-3}	175	187	30	17	313	175	233	50	33	381
	10	0	175	248	64	43	414	175	280	82	61	471
		10^{-4}	175	247	63	43	412	175	279	81	60	469
		10^{-3}	175	239	56	38	396	175	270	73	53	448
40	5	0	175	170	64	34	344	175	204	96	62	423
		10^{-4}	175	170	63	34	343	175	203	95	61	421
		10^{-3}	175	164	55	28	326	175	195	83	50	394
	10	0	175	203	95	61	421	175	223	116	83	474
		10^{-4}	175	203	94	61	420	175	223	115	83	473
		10^{-3}	175	199	88	55	406	175	218	108	75	456

APPENDIX C

Catching equation for fish with 3 degrees of freedom in the path of a bridle

1 INTRODUCTION

The analysis of the catching mechanism described in this paper has been concerned with fish movements in 2 dimensions only. However, the effect of a vertical component of fish movement could be incorporated in the 2-dimensional equations, and it is the purpose of this appendix to show how this may be done. Practical results could be obtained either by postulating values of the parameters or, alternatively, by applying measured values where a sufficient range available.

In the first instance, a more general approach to the 3-dimensional problem is given, but this necessarily contains more simplifying assumptions than were previously required as otherwise the physical significance of the equations would be hidden by their complexity.

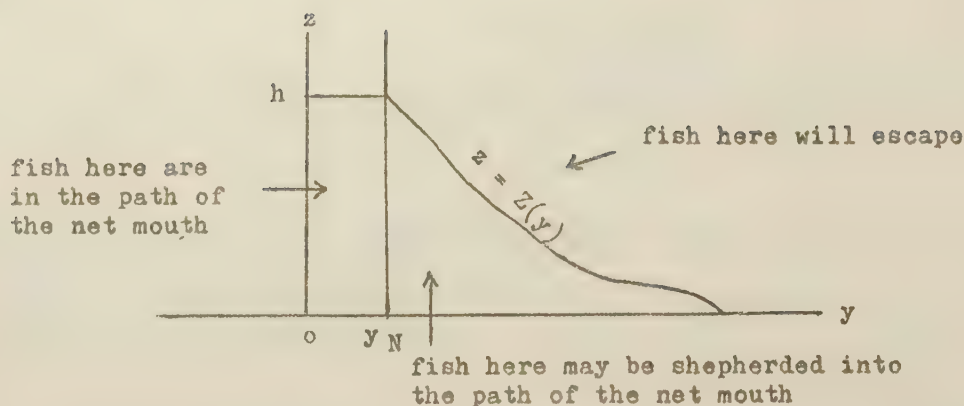
The scaring effect of bridles alone has been considered in the following analysis. Certainly, the contribution to the catch of the bridles seems to be greater than that due to the boards, as demonstrated by the results in Table I, but in any case the effect on catch of a vertical fish movement in response to a scare would be expected to increase with the number of interactions between a given fish and the scaring device. It has already been postulated, in the derivation of equations (4.13) that a given fish will interact only once with a board while the number of interactions with a bridle would be much larger. Thus the change in z-coordinate of a fish following a reaction to a board would be expected to be small, which would allow the analysis described in section (4.4) to be used to modify the following theory to include board effects.

2 GENERAL EQUATIONS

The origin of coordinates is taken on the sea bed, with the z axis passing through the centre of the headline. The fish density at point (x, y, z) is $\rho(y, z)$. The x-dependence of this quantity need not be considered if the fish are assumed not to react with one another, and in this case $\rho(y, z)$ can be taken to be the actual density averaged, at the beginning of a haul, over all values of x which will be covered by the trawl operation.

Suppose that for every y there exists a critical height $Z(y)$, defined as follows: if a fish is at a point (x', y', z') for which $z' > Z(y')$, it will escape on reacting to the bridles, if not on the first reaction certainly before it can be shepherded into the mouth of the net. On the other hand, for $z' < Z(y')$, provided the fish reacts favourably to a bridle which approaches within the reaction distance R_g (i.e. does not ignore or pass over the bridle) then the fish will end up in the path of the net mouth. The probability of a favourable reaction each time a sweep approaches to within R_g is ϵ_g . Referring to figure C1, this condition is shown diagrammatically. The practical significance of $Z(y)$ is that the volume swept by the area under the curve is the effective sieving volume, in which all fish would be caught if ϵ_g were unity.

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Fig. C1 Definition of $Z(y)$

Thus the catch per unit time due to bridle shepherding is

$$C_2 = V_T \int_{y_N}^{y_B} \int_0^{Z(y)} \epsilon_S n(y,z) \cdot \rho(y,z) dz dy \quad (C1)$$

where $n(y,z)$ is the number of times a fish starting at (y,z) reacts to a bridle before arriving in the net mouth.

As a fish has been assumed to take a finite number of non-zero steps during the shepherding process, in the absence of variation about the mean $Z(y)$ would be expected to be a discontinuous function, similar to that shown in figure C2.

Fig. C2 Typical unsmoothed Z function

However, because of considerable fluctuations in mean behaviour, due to variable lengths etc., a practical $Z(y)$ function should be regarded as comprising a large number of such curves superimposed, each one being dependent on one feature of one fish. Thus an experimentally determined $Z(y)$ function should not show any discontinuities.

Further application of this argument suggests that we may replace other theoretically discontinuous functions, such as $n(y,z)$, by a continuous mean function. In the latter case, errors arising from the substitution should be small provided that n is reasonably large. Assume that a fish reacts with probability ϵ_S to a bridle at a distance R_S by swimming away from it in the plane at right angles to the bridle. The fish swim a total distance s , during which time it rises a distance a , and then stops. It does not substantially move from this position until a bridle is again detected at a distance R_S , when the above behaviour is repeated. Thus we can write:

$$n(y, z) = \int_{y_N}^y \frac{dy}{\cos\theta \sqrt{(s^2 - a^2)}} \quad (02)$$

In the general case s and a need not be constant, but one or both could vary with y and/or z .

It remains to formulate $Z(y)$ in terms of measurable parameters. Those fish in the region $z > Z(y)$ escape because they rise to a height of at least R_g or the headline height h , whichever is the smaller, before they are herded to the region $y < y_N$. In the former case the fish no longer respond to the bridle when $z > R_g$, and in the latter they are not caught because they pass over the headline.

Over one reaction, a fish changes its y coordinate by an amount $-\cos\theta \sqrt{(s^2 - a^2)}$, and so

$$Z(y) = h - \int_{y_N}^y \frac{a \, dy}{\cos\theta \sqrt{(s^2 - a^2)}} \quad (03)$$

Equation (03) shows that $Z(y_N) = h$, and that $Z(y)$ decreases monotonically with increasing y , as would be expected. Negative values of $Z(y)$ are, of course, meaningless and so we write

$$Z(P) = 0 \quad (04)$$

$$Z(y) = 0, \quad y > P \quad (05)$$

P is a value of y such that no fish are caught from the region $y > P$. This means that an increase in bridle length above $(P - y_N)/\sin\theta$ would not produce any increase in catch.

Special cases

To obtain further information from equations (01-5), it is necessary to specify s , a and P in greater detail.

Hypothesis 1, P , s and a are independent of y and z .

With each reaction a fish will change its z coordinate by a and its y coordinate by $-\cos\theta \sqrt{(s^2 - a^2)} \frac{1}{2}$. The unsmoothed $Z(y)$ is defined by the following equations, where n is the number of reactions before the fish reaches the net mouth.

$$\frac{y - y_N}{\cos\theta \sqrt{(s^2 - a^2)}} = n + \Delta n - 1, \quad 0 \leq \Delta n < 1, \quad n \geq 1 \quad (06)$$

$$z = h - n a, \quad n < \frac{h}{a} - 1 \quad (07)$$

$$z = 0, \quad n > \frac{h}{a} - 1 \quad (08)$$

For the purpose of analysis, equations (06-8) are conveniently replaced by the smoothed curve, from (03):

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$$Z(y) = h - \frac{a(y - y_N)}{\cos\theta \sqrt{(s^2 - a^2)}} \quad (C9)$$

$$\text{for } y_N \leq y \leq y_N + \frac{h \cos\theta \sqrt{(s^2 - a^2)}}{a}$$

$$= 0 \quad \text{otherwise}$$

A similar smoothed approximation is required for $n(y)$, i.e. from (C2):

$$n(y) = \frac{y - y_N}{\cos\theta \sqrt{(s^2 - a^2)}} \quad (C10)$$

Substituting in (C1) we then get

$$C_2 = V_T \int_{y_N}^{y_B} \epsilon_s \frac{y - y_N}{\cos\theta \sqrt{(s^2 - a^2)}} \left[\int_0^{Z(y)} \rho(y, z) dz \right] dy \quad (C11)$$

$\rho = \rho(y, z)$ is a constant. Then (C9) and (C11) combine to give

$$C_2 = \rho V_T \int_{y_N}^P \epsilon_s \frac{y - y_N}{\cos\theta \sqrt{(s^2 - a^2)}} \left(h - \frac{a \{y - y_N\}}{\cos\theta \sqrt{(s^2 - a^2)}} \right) dy$$

$$\text{where } P = \min \left\{ y_B, y_N + \frac{h \cos\theta \sqrt{(s^2 - a^2)}}{a} \right\} \quad (C12)$$

i.e.

$$C_2 = \rho V_T \frac{\cos\theta \sqrt{(s^2 - a^2)}}{\log \epsilon_s} \left[h \left(\epsilon_s^{\frac{P - y_N}{\cos\theta \sqrt{(s^2 - a^2)}}} - 1 \right) - \frac{a}{\log \epsilon_s} \left\{ 1 + \epsilon_s^{\frac{P - y_N}{\cos\theta \sqrt{(s^2 - a^2)}}} \left(\frac{P - y_N}{\cos\theta \sqrt{(s^2 - a^2)}} \log \epsilon_s - 1 \right) \right\} \right] \quad (C13)$$

Hypothesis 2 s and a are independent of y and z . p is independent of y but varies linearly with z .

The equations become more complicated when a non-uniform density is considered. Take $p(y, z)$ now as:

$$\begin{aligned} p(y, z) &= p_b \left(1 - \frac{z}{z_m}\right), \quad z \leq z_m \\ &= 0, \quad z > z_m \end{aligned} \quad (C14)$$

where p_b is the density at the sea bed, assumed independent of y .

Hence, from (C9), (C11) and (C14):

$$\begin{aligned} C_2 &= p_b V_T \int_{y_N}^P \epsilon_s \frac{y - y_N}{\cos \theta \sqrt{(s^2 - a^2)}} z(y) dy \\ &\quad - \frac{p_b V_T}{2 z_m} \cdot \int_{y_N}^P \epsilon_s \frac{y - y_N}{\cos \theta \sqrt{(s^2 - a^2)}} z^2(y) dy \end{aligned} \quad (C15)$$

The first term in (C15) is of course given by (C13). Denoting this part by $C_2(13)$ the second term is then evaluated to give:

$$\begin{aligned} C_2 &= C_2(13) - \frac{p_b V_T}{z_m} \left\{ \frac{h^2 \cos \theta \sqrt{(s^2 - a^2)}}{2 \log \epsilon_s} \left(\epsilon_s^{\frac{P - y_N}{\cos \theta \sqrt{(s^2 - a^2)}}} - 1 \right) \right. \\ &\quad + \frac{h a \cos \theta \sqrt{(s^2 - a^2)}}{(\log \epsilon_s)^2} \left[1 + \epsilon_s^{\frac{P - y_N}{\cos \theta \sqrt{(s^2 - a^2)}}} \left(\frac{P - y_N}{\cos \theta \sqrt{(s^2 - a^2)}} \log \epsilon_s - 1 \right) \right] \\ &\quad - \frac{a^2 \cos \theta \sqrt{(s^2 - a^2)}}{(\log \epsilon_s)^3} \left[\epsilon_s^{\frac{P - y_N}{\cos \theta \sqrt{(s^2 - a^2)}}} \right. \\ &\quad \left. \left\{ 2 - \frac{2 \log \epsilon_s}{\cos \theta \sqrt{(s^2 - a^2)}} (P - y_N) + \frac{(\log \epsilon_s)^2}{\cos^2 \theta (s^2 - a^2)} (P - y_N)^2 \right\} - 2 \right] \left. \right\} \end{aligned} \quad (C16)$$

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Reduction of 3-dimensional theory to a 2-dimensional form

The key to the transformation lies in the parameter

$$\epsilon_B = \epsilon_{s0} + \beta(y' - y) \quad (C17)$$

Consider an individual fish. Its probability of escape can be considered to have two components, one due to 3-dimensional movement and the other due to effects which can be thought of on the basis of a 2-dimensional model. Thus

$$\epsilon_{s0} = \epsilon_{s02} \cdot \epsilon_{s03} \quad (C18)$$

and

$$\beta = \beta_2 + \beta_3 \quad (C19)$$

Where the suffix 3 refers to the component due to vertical movement. In a practical case, these parameters are averages over a number of fish. By definition no fish in $z > R_S$ will react on the first encounter, so we have

$$\epsilon_{s03} = \frac{\int_0^{R_S} \rho(y'z') dz'}{\int_0^{z_m} \rho(y'z') dz'} \quad (C20)$$

if $R_S \leq z_m$, or $\epsilon_{s03} = 1$ otherwise.

ϵ_{s03} could be a function of y' . In the case of β_3 , the path followed by a fish first reacting at a point (x', y', z') must be determined. Ignoring the x-coordinate, the relationship between the y and z coordinates of a point on its path, i.e. $z = z(y)$, is described by:

$$z(y) = z' + \int_{y'}^y \frac{a dy}{\cos \theta \sqrt{s^2 - a^2}} \quad (C21)$$

a may, of course, be a function of z as well as y, so the above integral must be taken along the line $z = z(y)$. That is $a \equiv a(y, z) \equiv a(y, z(y))$.

The differential equation for z is

$$\frac{dz}{dy} = \frac{a(y, z(y))}{\cos \theta \sqrt{s^2 - a^2(y, z(y))}} \quad (C22)$$

which can be solved to give $z(y)$, subject to the boundary condition $z = z'$ at $y = y'$, once $a(y, z)$ is specified in functional form. $z(y)$ must now be written as $z(y) \equiv z(y, y', z')$ as it will depend on all three parameters.

Taking the case $h > R_S$, the fish will escape if and when it reaches a point y_1 , for which

$$z(y_1, y', z') = R_S \quad (C23)$$

Hence y_1 can be described by

$$y_1 = F(y', z', R_S) \quad (C24)$$

where F is some function. The equation for β_3 can now be formulated. It is

$$\beta_3 = \frac{\int_{Z(y)}^{z_m} p(y', z') \frac{\epsilon_{s03}}{y' - F(y', z', R_S)} dz'}{\int_0^{z_m} p(y', z') dz'} \quad (C25)$$

The upper integral is taken from the lower limit of $Z(y)$, because by definition no fish in the region $z < Z(y)$ can rise above R_S .

THE REACTION OF SOME FISHES IN AN ELECTRIC FIELD

by

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Abstract

The work deals with some physiological aspects of the reaction of different fish species in electric fields of pulsating and constant current with special reference to the possibility of their use in fishing. The mechanism of anodal reactions and the role of different parts of nervous system in these reactions are described.

REACTION DE CERTAINS POISSONS DANS UN CHAMP ELECTRIQUE

Résumé

La communication traite de certains aspects physiologiques de la réaction de diverses espèces de poissons dans des champs électriques de courant intermittent ou continu, en s'attachant particulièrement aux possibilités d'application à la pêche. Les auteurs décrivent le mécanisme des réactions anodiques et le rôle qu'y jouent différentes parties du système nerveux.

LA REACCION DE ALGUNOS PECES EN UN CAMPO ELECTRICO

Extracto

El estudio se ocupa de algunos aspectos fisiológicos de la reacción de diferentes especies de peces en campos eléctricos de corriente ondulatoria y continua, con especial referencia a la posibilidad de emplearlos en la pesca. Se describen el mecanismo de las reacciones anódicas y la función de las distintas partes del sistema nervioso en estas reacciones.

1 INTRODUCTION

There are currently numerous investigations underway in the Soviet Union and other countries directed toward the development of new fishing gear and methods. Success of these efforts will depend to a great degree on knowledge and understanding of the reactions of fish to various artificial stimuli such as electricity, light, sound and odours.

In conjunction with other techniques the application of electrical stimulation appears to offer possibilities for development of more efficient harvesting systems. Many investigations of the reaction of fish to electricity have been made but the results of these are somewhat contradictory. The absence of concrete data on fish response to electricity and on the physiological factors involved is one of the primary reasons that electrical fishing has not developed.

In order to acquire pertinent electrical and physiological data, comprehensive electrical experiments were conducted at the Klipeda office of Hyproribflot. The primary objective of this work was to study in detail the responses of commercial marine fishes in various electrical fields with a view to establishing optimum electrical parameters of pulsed current for producing electrotaxis (anodal reaction) and electronarcosis. Also, the nature of the physiological factors resulting in electrotaxis was investigated.

The primary studies were related to reactions of fish to pulsed current rather than continuous current, because of the applications of this type in commercial marine fisheries. The practical application of continuous current in seawater is severely limited due to the enormous energy requirements for producing even a small effective electric field. This is directly related to the very high electrical conductivity of seawater.

The experiments were performed on commercial species from the Baltic Sea which included: Baltic herring (Clupea harengus membras), Baltic cod (Gadus morhua), smelt (Osmerus eperlanus eperlanus) and vimba (Vimba vimba).

2 EXPERIMENTAL RESULTS

Initial tests demonstrated that typical response patterns were observed with all species tested when using uninterrupted current. As the strength of the electrical field was gradually increased the initial response was an excitement which changed to a directed movement toward the anode (electrotaxis) and finally, loss of mobility and equilibrium (electronarcosis). The same responses were observed when pulsed current was used except that the initial response was more violent due to separate stimulations provided by the pulses.

2.1 Effect of pulse shape

Three pulse shapes were tested, (a) a pulse with a rapid rise-time, (b) a pulse with a moderate rise-time and (c) an angular pulse. An electrotactic response was obtained with all pulse forms tested. The pulse shape affected only the electrical power required to obtain the response. Minimum power consumption was required with the fast rise-time pulse when the pulse width was less than one ms. When the pulse width was greater than one ms the power required was the same for the fast and moderate rise-time pulse widths. The angular pulse required the greatest power.

2.2 Effect of pulse width and pulse rate

In these tests the body voltage, defined as the potential difference between head and tail, was used to measure the effect of pulse width in producing a threshold

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electrotactic response. In tests on Baltic herring using a pulse width of 0.3 to 0.5 ms the threshold body voltage was 1.2 to 2 volts. Decreasing the pulse width to 0.1 to 0.05 ms increased the threshold body voltage considerably. Decreasing the pulse rate below 10 pps required the increasing of the body voltage for a threshold response.

2.3 Electrotaxis response

The threshold parameters described above compare favourably with those described by other authors (Danzon 1956 and McBry 1956). However, the results of the experiments reported here show that although a threshold response is elicited a clear electrotaxis response is not obtained - the fish (Baltic herring) are not held near the anode.

To investigate this phenomenon a series of experiments were performed to determine how various pulse frequencies and widths influenced response patterns when the fish were near the anode. Photographic records of the behaviour patterns were obtained and used for detailed studies. The results of these experiments demonstrated that the electrotaxis effect could be improved in two ways: (1) when using a short pulse width, increase the pulse rate and (2) when using a low pulse rate, increase the pulse width. For example when the pulse frequency was increased from three to 25 pps (pulse width 0.5 ms) the number of fish showing a clear electrotaxis response increased from 7 percent to 59 percent; and when the pulse width was increased from one to 24 ms electrotaxis responses increased from 17 percent to 70 percent. These experiments also revealed distinct differences in the nature of the response between the two methods of stimulation. When using frequencies of 20 pps and greater, electrotaxis was improved, but in addition electronarcosis also increased markedly. When using the long pulse and low frequency the electronarcotic effect was not nearly as pronounced.

In addition, the experiments showed that there is a frequency range within which the electronarcotic response is significantly more pronounced than at other frequencies. For Baltic herring this range was 80 to 200 pps and for cod 40 to 100 pps.

2.3.1. Response variations by species

Distinct differences of threshold response levels by species were observed during the experiments. Smelt, which are similar to Baltic herring in size and body structure require a greater body voltage to elicit a response than the herring.

In experiments with cod a distinct difference in the electrotactic response was found between constant and pulsed current stimulation. In the constant current field a distinct electrotaxis was achieved whereas in the pulsed field this was not the case. Increasing the pulse rate slightly did not achieve the desired result but instead resulted in electronarcosis. The results of the initial experiments demonstrated that the most distinct electrotaxis was achieved with continuous current stimulation or with pulsed current of wide pulse width and low pulse rate. However, due to the enormous power requirements for producing these in sea water they will have limited application in marine fisheries.

2.4 Experiments with a non-homogeneous electric field

Due to the prohibitive power requirements of continuous current, subsequent experiments were directed toward investigation of response patterns to stimulations with various pulse characteristics. For these tests a cylindrical tank of 15 m diameter and 2 m depth was used. The electric field in these experiments was not homogeneous within the tank.

In experiments with Baltic herring, using 15 to 20 pps, an electrotaxis response was achieved with the fish concentrating 1.5 to 2 m from the anode. However, the fish were very mobile and did not form compact aggregations. Increasing the pulse frequency or strength increased the number of fish narcotised but did not increase the density of congregation. A similar pattern was observed with smelt.

However, the cod's behaviour in the non-homogeneous field, as in the homogeneous one, differed significantly from that of herring and smelt. With a pulse rate of 3 to 5 pps the cod turned toward the anode. However, this was followed only by excited swimming with no gathering near the anode. Increasing the pulse rate or frequency did not improve the electrotactic effect but only enlarged the zone of electronarcosis.

2.5 Further experiments on electrotaxis

The results of the previous experiments were in general agreement with those obtained in the homogeneous electric field and confirmed a deficiency in electrical effectiveness with pulsed energy. Consequently, additional experiments were made with a view to significantly improving the electrotaxis response. The most significant improvement in the response was achieved by superimposing a continuous current of constant amplitude onto a pulsed current. The continuous current amplitude was 5 to 10 percent of the pulse amplitude. With this stimulation the electrotactic pattern was approximately equal to that achieved in the experiments described earlier using continuous current of much greater amplitude. Also, the effective range of this stimulation was equal to that of pulsed current alone. Even cod, which did not show a clear electrotaxis in previous experiments formed compact aggregations at the anode.

3 PHYSIOLOGICAL EXPERIMENTS

In addition to knowledge regarding the effect of various electrical parameters on the response of fish it is also important that information regarding physiological factors be acquired. Since there is little agreement in reported experiments designed to investigate this phenomenon a series of tests were made to further examine the physiological nature of the response to electrical stimulation. Initial tests involved investigating the possibility of skin reception and the effect of various parts of the brain. The ability to produce an electrotaxis response was found to be independent of these. The principal organ involved in triggering the response appears to be the spinal cord. This was suggested by tests involving surgically isolating the spinal cord as well as its parts. It was corroborated by tests involving measurement of the time of reaction when the fish was oriented both parallel and perpendicular to the flow of current. Thus, these results appear to contradict those reported by Blancheteau et al. 1961 which suggest the dominant role in eliciting electrotaxis is played by the brain.

Without rejecting the possibility of ascending and descending nerves of the reticulo-spinal system responding to the electrical stimulus, to which Blancheteau et al. give the dominant role, we suggest the mechanism of electrotaxis is provided by the automatic locomotion apparatus of the spinal cord which produce the undulative movement of fish. This apparatus functions only in animals whose locomotion is provided by undulating movements of the body, particularly its posterior region.

In order to study the influence of different methods of locomotion on producing electrotaxis experiments were performed with different species of fishes, in which swimming movements the body-tail muscles do not play a dominant role. The results of these experiments showed that for flounder (Pleuronectus flesus), diodon (Diodon hystrix), file-fish (Aluterus punctatus) and scorpion fish (Scorpena angolensis) electrotaxis was absent. In butterfly blenny (Cypselurus lineatus) Pagrus sp. and others the electrotaxis reaction was not clear. Only for fishes in whose swimming movements the predominant role is played by body-tail muscles, was electrotaxis pronounced. These included herring, sardine, smelt, scad and vimba. Thus all the results of our experiments suggest that electronarcosis of fishes is the result of polar forcing of electric current on the automatic locomotion apparatus of the spinal cord.

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4 REFERENCES

Barry, B. McK., The effect of electric fields on marine fishes. Mar.Res.,
1956 Mar.Res., (1):32 p.

Blancheteau, M. et al., Etude neurophysiologique de la pêche électrique (Courant
1961 continu). Bull.Cent.Etud.Rech.scient., Biarritz, 3(3):275-382

Denzer, H. W., Die Elektrofischerei. Handb.Binnenfisch.Mittleur., (5)
1956

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FISH BEHAVIOUR IN THE AREA OF THE TRAWL AS STUDIED BY BATHYPLANE

by

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Abstract

The bathyplane ATLANT is a manned towed body weighing 2 t and capable of being towed at 6 kn with depths of submersion up to 150 m. Photographs and plans are given. Reactions of fish to the trawl gear is considered in four regions: the first between otter boards and wing ends, where cloud-like eddy trail is important; the second from the wing ends into the belly where herding is important; the third after part of the belly where fish density reaches a critical stage and fourth the fish reactions in the codend.

ETUDE, AU MOYEN DU "BATHYPLANE", DU COMPORTEMENT DES POISSONS AUTOUR ET A L'INTERIEUR DU CHALUT

Résumé

Le bathyplane ATLANT est un engin à équipage pesant 2 tonnes et pouvant être remorqué à une vitesse de 6 noeuds et à une profondeur maximale de 150 mètres. La communication renferme des photographies et des plans de l'appareil. Les réactions des poissons autour et à l'intérieur du chalut ont été étudiées dans les quatre zones suivantes: 1) entre les panneaux et l'extrémité des ailes, où les remous, qui donnent naissance à une sorte de nuage, jouent un grand rôle; 2) de l'extrémité des ailes au ventre, où l'effet de rassemblement est important; 3) en arrière du ventre, où la densité des poissons atteint un niveau critique; 4) dans le coul-de-chalut.

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EL COMPORTAMIENTO DE LOS PECES EN LA ZONA
DE LA RED DE ARRASTRE ESTUDIADO DESDE UN BATISCAFO

Extracto

El batiplano ATLANT es un sumergible tripulado, de 2 toneladas de peso, que puede ser remolcado a una velocidad de seis nudos, y que alcanza profundidades de inmersión hasta de 150 metros. Se presentan fotografías y planos. Se consideran las reacciones de los peces ante la red en cuatro regiones: la primera entre las puertas y los extremos de las alas, en donde es importante la estela, de aspecto de nube; la segunda desde los extremos de las alas hasta el vientre, en donde es importante el agrupamiento de los peces; la tercera a partir de un sector del vientre, en donde la densidad de los peces alcanza una fase crítica; y la cuarta el copo, y las reacciones de los peces en él.

1 INTRODUCTION

Special Experimental AtlantNIRO Design Office has been engaged in underwater observations on the trawl and fish behaviour in the trawl area since 1963. Bathyplane ATLANT has been the main technical means for the solution of this problem. During 1963 to 1966, 130 observations had been made from the bathyplane ATLANT with a duration of 2.5 h each. On the basis of these observations preliminary conclusions characterizing fish behaviour in the trawl area may be drawn.

2 DESCRIPTION OF BATHYPLANE

ATLANT is towed on a cable-rope. Within the bathyplane a pilot-observer is placed on a special chair and fully isolated from the surroundings. Four illuminators having a diameter of 140 mm provide good observation from within the bathyplane and allow filming. There are five projectors with mirrored lamps of 500 g each inside streamlined housings for outward illumination. Besides there is a pulsed electronic lamp of 2000 joules.

Electric energy is supplied to the bathyplane on a cable-rope from the towing vessel. Standard 220 v 50 cycles a.c. is used. The cable-rope has a screened-telephone core for continuous two-way contact between pilot-observer and two communication points shipboard.

In the free condition, that is without towing strain, the bathyplane has positive buoyancy which may be changed from 50 to 150 kg, by blowing off the ballast tanks. The submersion of the bathyplane takes place during the towing by virtue of negative hydrodynamic force on the driving planes (Fig. 3). The depth of the bathyplane submersion depends largely on the length of cable veered, but this depth may be finely controlled by the pilot-observer by means of horizontal rudders (Fig. 4). The vertical rudder allows change of bathyplane position to the right or to the left of the towing direction.

Depth sounders provide control of the submersion depth and an echo sounder measures the distance to the bottom and records on a special tape. The echo sounder is also used for measuring the position of various trawl parts in relation to the bottom. Regeneration plant provides the pilot-observer with air supply for 16 h. Principal dimensions are:

length	4.45 m
breadth	4.3 m
weight	1.9 t
top submersion depth	150 m
top towage speed	6 kn

3 OBSERVATIONS

The process of trawling can be followed by the bathyplane ATLANT from the beginning to the end of the haul. Any trawl point or any trawl area is accessible for observation from the otter boards to the codend (Fig. 6).

Most of the underwater trawl observations took place at the speed of 3.0 to 4.2 kn. The trawl had the following operational dimensions:

length of the headline	33 m
vertical opening from	5.0 to 6.0 m
distance between the wing ends, about ..	16 m
length of selvage	50 m

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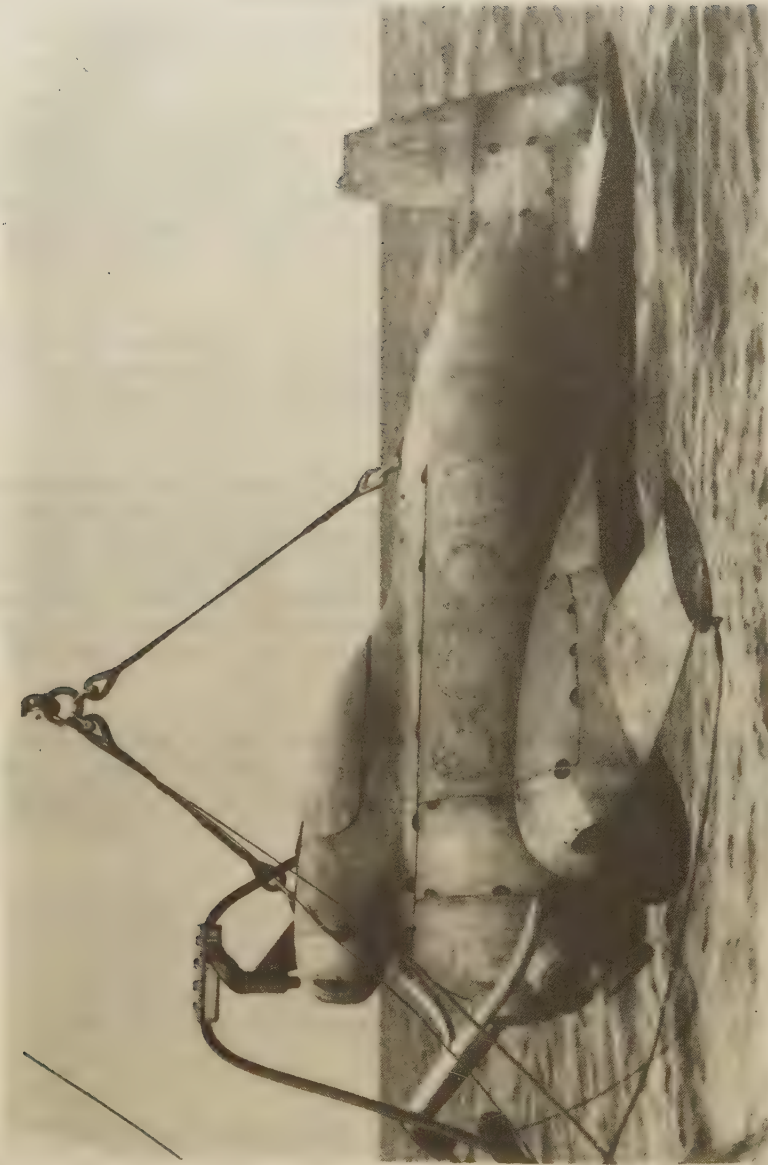


Fig. 1 The bathyplane ATLANT

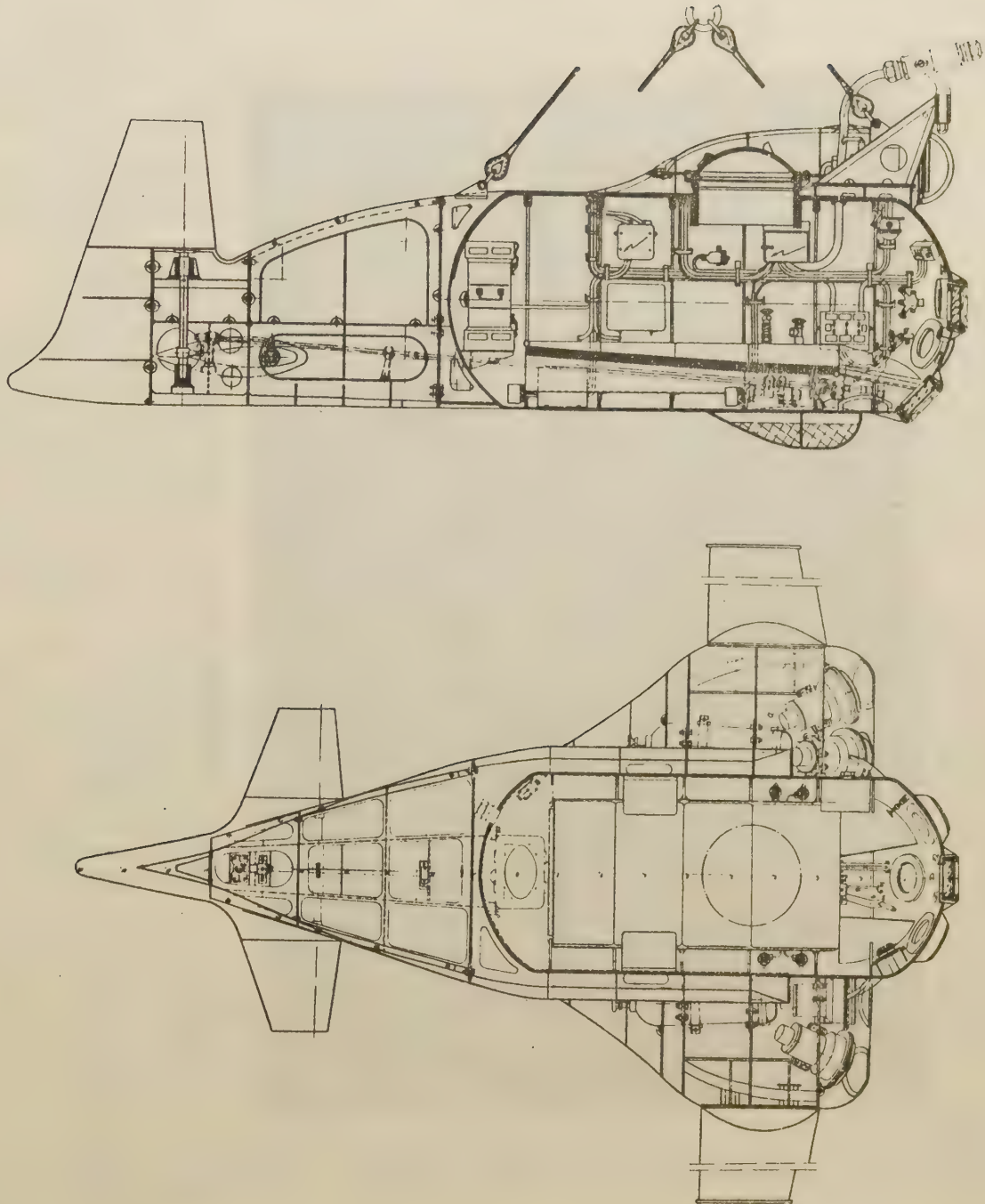


Fig. 2 Plans of the bathyplane



Fig. 3 Underwater view of the bathyplane

The trawl was rigged with otter boards of the Matrosov type with an area of 3.5 m. The distance between the doors and wing ends was 50 m. In order to reduce bathyplane influence on fish behaviour in the trawl area, the observations took place at as large a distance as allowed by the water transparency in the area of trawling. It should be noted that fish were frightened by the bathyplane in the forward part of the trawl, in the area of otter doors, cables and over the large mesh square only when it moved relative to these. In the belly and the bag, fish within the net body did not react to the bathyplane even though the distance between the fish and the bathyplane at times reduced to 20 to 30 cm. Perhaps this is explained by the screening effect of the webbing with its smaller meshes in these areas.

From the point of view of fish behaviour the whole complex doors-cables-trawl may be divided into four sections (Fig. 5), in each of which fish behaviour has its own peculiarities.

3.1 The first section

This extends from the otter boards to the forward wing ends including cables and bare-ends. Strong eddies in the wake of the otter boards are the most typical feature of this section. The area of the eddy trains are filled with small particles of silt and resembles a dense smoke-screen extending along the cables and the wings towards the trawl bag (Fig. 6). In the trawling speed range the turbulent train was situated outside of cables and wings with only the first 15 to 20 m of cables nearest the otter board within the train. The distance between the eddy train boundary and the cable increases as one moves aft and reaches near the wing 1 to 2 m at the trawling speed of 3 kn and 4 to 6 m at 4.2 kn. The distance between the most upper point of the train and the ground in its cross section near the door was equal to the height of the latter and in the wings area was 4 to 6 m.

It may be concluded from the observations that all kinds of fish react to the eddy trains. In order to avoid getting into it fish remain within space between the cables, that is they move into the path of the net body. There was not a single case when bottom fish, skate (Raja), flounder (Pleuronectes), grouper (Epinephelus) and others left the bottom to pass above the eddy train. Other species of fish (soad-Trachurus, mackerel-Scombrus, rorqual-Balaenoptera physalus) reacted to the train in just the same way except for a few cases when small groups of fish (from 1 to 5-6 individuals with intervals of 20 to 40 cm between them) went away from the area of trawling above the upper eddy train boundary. It should be noted that before contact with the train fish were in a layer extending up to 3 to 4 m from the bottom.

Thus the above-mentioned trawl parts (doors and cables) are carrying out very important functional work: they must limit fish escaping to the sides and concentrate it into the path of a trawl movement. An additional false headline has much the same function when catching fish of the herring family, which are very mobile in the vertical direction. The vertical opening of the trawl may be increased insignificantly but the turbulent train extending behind the kites also makes a "roof" above the area in front of the trawl tending to keep the fish from rising.

Naturally, the question arises of how fish react to the turbulent trains. Perhaps, it reacts differently depending on the conditions. When there is enough illumination and water transparency, fish see a turbulent silt filled cloud at a considerable distance from it.

When there is not enough illumination and the water transparency is not good, then fish may react to the turbulent trains by means of the lateral line organ, but at smaller distances. Perhaps, in this case pressure waves occurring in the area of turbulent water displacement behind the otter boards are perceived by fish.

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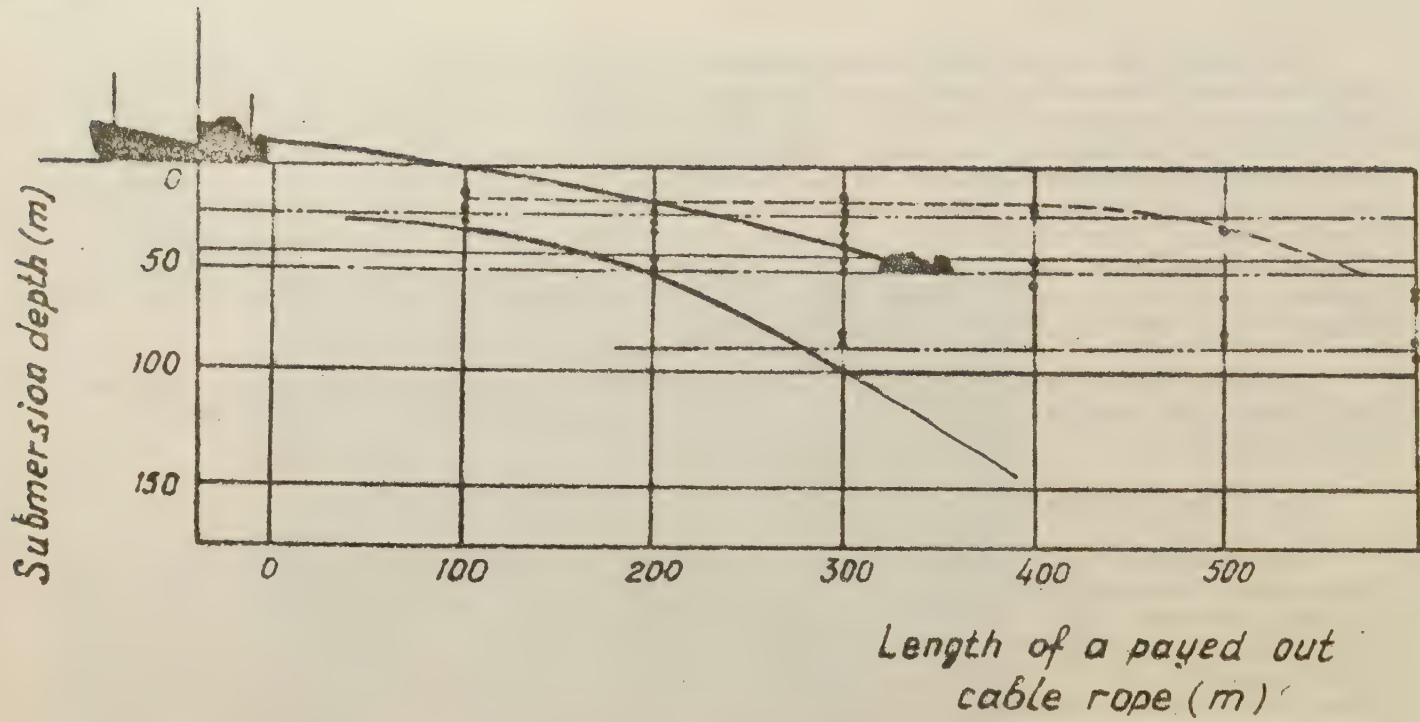


Fig. 4 Graph of cable to depth ratio

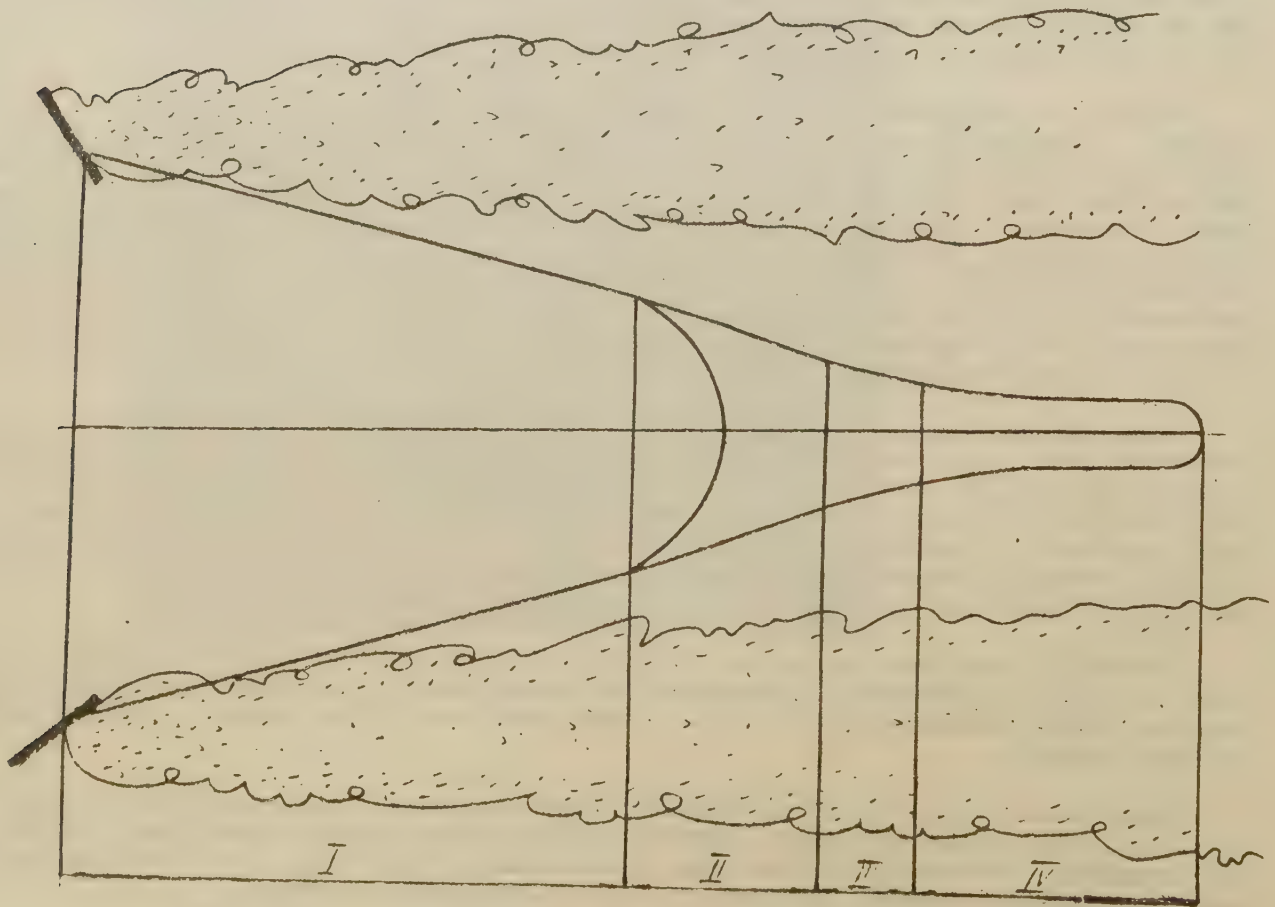


Fig. 5 The four behavioural sections of the trawl and the eddy trail



Fig. 6 Sweep cable and eddy trail



Fig. 7 Underwater view of the codend

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In any case fish behaviour in the first section is characterized by fish moving away from the approaching doors, cables and strong turbulent eddy trains.

3.2 The second section

This lies between the front part of the wings and the back part of the belly.

In this section fish between the wings and within the bag do not try to escape from the trawl through the meshes, though the mesh size would easily allow this. As the trawl approaches the fish begin to move forward trying to swim out of the trawl. For example at a trawling speed of 3.8 to 4.0 kn scad makes short bursts allowing it to gain distances of 2 to 3 m with respect to the trawl, but very soon it begins to fall back into the trawl bag. In this section fish escaped from the trawl only in cases where it appeared near the trawl and touched it with tail or fin. In such cases fish quickly lost speed, became pressed to the webbing and passed out of the trawl because of the big mesh size in that area. Besides a large percentage of fish do not even try to escape from the trawl but pass straight into the bag. In short we can say that in the second section fish try to find a big escape opening in the net body.

3.3 The third section

This includes the last panel of the belly and the conic part of the trawl bag. In this section the ever-narrowing net body reaches a critical size and fish rush about the net walls seeking any small hole or to come out through a mesh. The length of this section along the trawl axis is about 5 to 6 m.

Thus the main mass of fish tries to escape from the trawl through the meshes, and the rest slides into the bag or tries to escape from it towards the trawl mouth. But at the trawling speed of 3.0 to 3.5 kn these attempts never reached success. Fish fell behind and rolled down in the bag. Thus we can say that in the third section fish try to escape from the trawl through the meshes.

3.4 The fourth section

This section comprises a cylindrical part of the bag together with the codend where the accumulation of catch takes place. Most of the fish caught in the trawl bag cannot resist actively. They are entrained in the swirling water and form a fish-water mass. This mass density increases towards the back part of the bag until the fish are packed close to each other. From the fish behaviour point of view, only the front part of the catch accumulation zone is interesting because the density of fish "packing" in the back part of the codend does not allow much movement (Fig. 7).

Carried along by the whirlpool, fish may be pressed on to the webbing and push through a mesh if the meshsize allows it. This process is accidental and does not much depend on the fish (we mean small fish, sardines, scad and morrhuall having sizes up to 20 cm), as the intensity of the water vortice exceeds the physical capabilities of the fish. This "boiling copper" occupies an area about 1.0 m before the solid catch mass.

4 CONCLUSION

Thus underwater observations on fish behaviour in the trawl and before the trawl mouth show that fish react differently to the different parts of the trawl. Factors such as illumination, water transparency, trawl shape, its sizes and the peculiarities of its construction have an influence on fish behaviour. Naturally the behaviour of each fish species is different though there is much that is common to all.

The work on fish behaviour studies in the vicinity of the trawl will be continued and the results mentioned above will be checked repeatedly as the constant development of underwater observation technique increases from year to year.

5 REFERENCES

- Martyshevskii, V.N., The effect of the eddy trails of the otterboards on the catching
1965 ability of trawls. Ryb.Khoz., 41(12):28-30 Also issued as Transl.Fish.Lab.,
Lowestoft, (80):5 p.
- , Account about works in RT-202 MUCSUN trip from 17th April to the 17th
1965 June 1965. Kaliningrad, AtlantNIRO Special Experimental Design Office
- , The effect of the eddy trails of the otterboards on the catching ability
1966 of trawls. Ryb.Khoz., 42(1):51-4 Also issued as Transl.Fish.Lab., Lowestoft,
(80):5 p.
- , Account about the trip RT-202 MUCSUN to the Mediterranean and Adriatic
1966 seas from the 4th August to the 2nd November. Kaliningrad, AtlantNIRO
Special Experimental Design Office
- Radakov, D.V. and V.R. Protasov, Rate of movement and some peculiarities of fish sight.
1964 Moskva, Nauka

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SONIC TAGS AND FLOATS AS A MEANS OF STUDYING FISH RESPONSE
TO NATURAL ENVIRONMENTAL CHANGES AND TO FISHING GEARS

by

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Abstract

Sonic tags and floats were attached to sturgeon and bream in the Rubinsk and Volgogradsk reservoir also in the Volga. Courses taken by the fish relative to bottom topography and water flow were plotted. Average swimming speeds and burst of speed were also measured. Interesting deflections of course occurred when the fish swam under an overhead 110 kv high tension cable. Magnetic field strength in the water was 0.6 oersted.

MARQUES ET FLOTTEURS SONORES POUR L'ETUDE DE LA REACTION DES POISSONS
AUX VARIATIONS NATURELLES DU MILIEU ET DEVANT LES ENGINS DE PECHE

Résumé

Des marques et flotteurs sonores ont été fixés à des esturgeons et à des brèmes dans les lacs artificiels de Rybinsk et de Volgograd ainsi que dans la Volga. On a relevé l'itinéraire suivi par les poissons par rapport à la topographie du fond et aux courants, en mesurant également les vitesses moyennes de nage ainsi que les pointes de vitesse. On a noté avec intérêt les déviations que les poissons apportaient à leur route lorsqu'ils passaient au-dessous d'un câble aérien à haute tension (110 kV). Dans l'eau, l'intensité du champ magnétique était de 0,6 oersted.

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MARBETES Y FLOTADORES SONICOS UTILIZADOS COMO MEDIOS
PARA ESTUDIAR LAS REACCIONES DE LOS PECES ANTE LOS CAMBIOS
EN EL MEDIO AMBIENTE NATURAL Y ANTE LOS ARTES DE PESCA

Extracto

En los embalses de Rybinsk y Volgogradsk, y también en el Volga, se pusieron marbetes y flotadores sónicos a esturiones y otros peces. Se trazaron los cursos seguidos por los peces en relación con la topografía del fondo y la corriente del agua. Se midieron también las velocidades medias de natación y los impulsos de velocidad. Cuando los peces nadaron bajo un cable de alta tensión de 110 kw, tuvieron lugar interesantes desviaciones en el curso seguido. La potencia del campo eléctrico en el agua era de 0,6 oersteds.

1 INTRODUCTION

New methods to lure or frighten fish for the purpose of increasing selective fishing effectiveness must be based on detailed knowledge of natural behaviour response of fishes in different natural and artificially created conditions.

To study these reactions and to track the fish, light floats (Hasler and Wisby 1958, Poddubny 1965) or sonic tags (Johnson 1960, Poddubny, Spector, Kidun 1966) can be used. Observations have been made on tagged fish placed into an extensive natural circle, confined by a wall of netting (Poddubny and Gordeev 1966).

This paper considers the principal results of the investigations of the natural behaviour of sturgeon (Acipenser gùldenstadtii Brandt), bream (Abramis brama L.) and blue bream (A. ballerus L.) carried out by the author in the Rybinsk and Volgogradks reservoir and also in the Volga from 1963 to 1966.

2 BEHAVIOUR OF STURGEON MIGRATING UPSTREAM TO THE BREEDING AREAS

Mature female and male Volga winter sturgeon, 182 in number and bearing small ultrasonic transmitters on their backs were released in the areas of the reservoir in which bathymetry, direction and velocity of flow, temperature, ph, electro-conductivity and oxygen content were measured during the experiment. Then individual and group tracking was carried out on the average for 17 hours (fluctuations 2-181 hours).

The receiver set, mounted on the attendant vessel monitored signals from the transmitter-tags up to distances of 2.5-3 kilometers and recorded their direction within 3°. The transmitters have an endurance of 2-50 days, minimum weight 35-40 g, carrier frequency 42-49 kc/s and impulse frequency 1-5 cps.

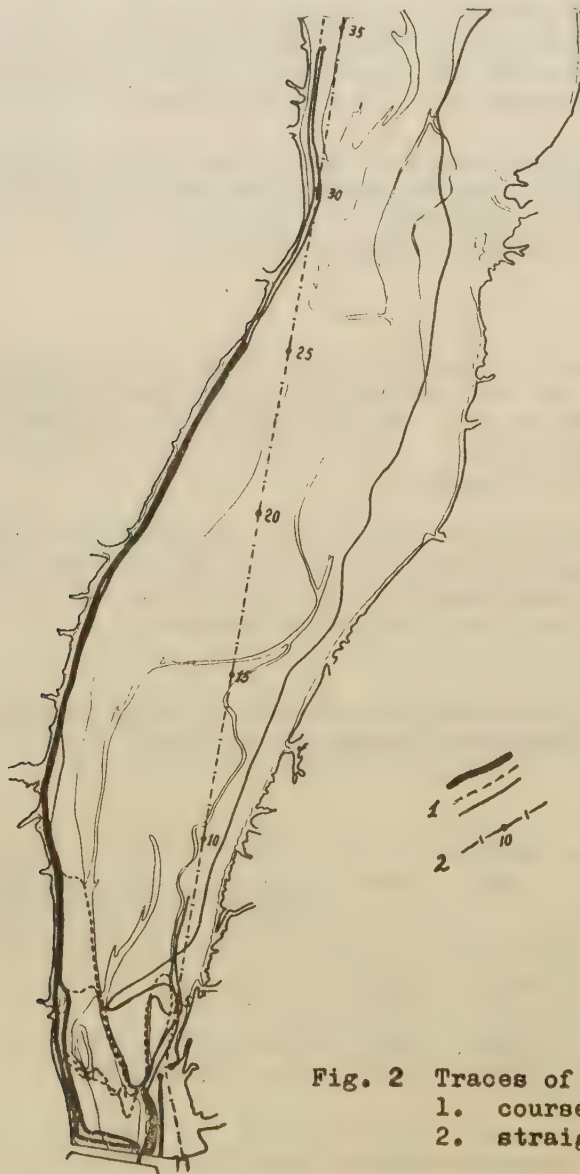
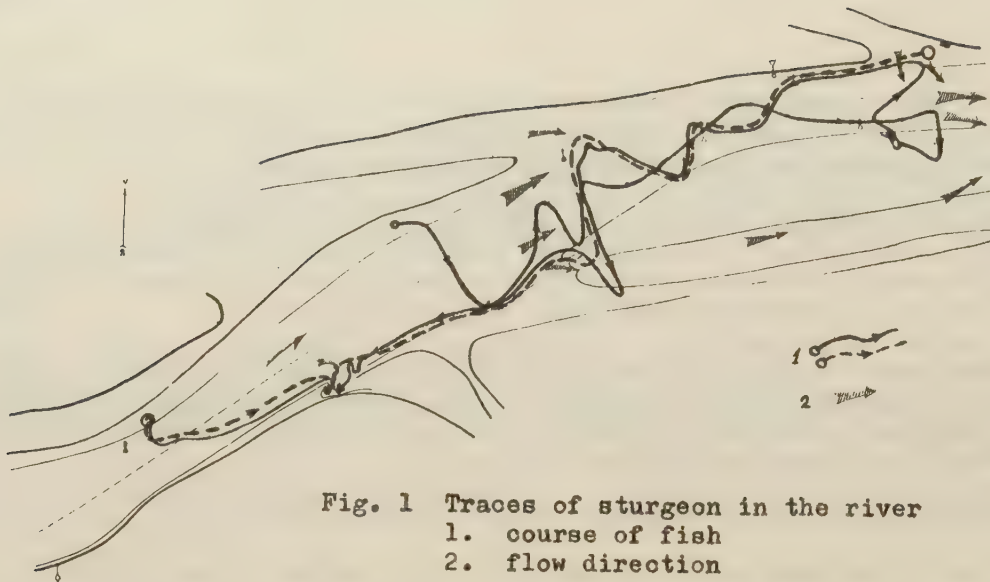
2.1 Courses of sturgeon

Both in the river (Fig. 1) and in the reservoir (Fig. 2) a striking coincidence in the courses taken by individual fish was noticed even for those released on different days and at different hours of the day, so long as they passed through areas with plain bottom relief and constant flow direction. Sharp alterations of course occurred in zones with steeper bottom contours and with eddies.

The ratio of straight line distance between start and finish to total distance swum is peculiar to all ecological situations but it is the more considerable when the fish swim near a dam or in zones with sluggish flow (Table I). In more regular current conditions males show less deviation from the general course.

TABLE I - Ratio of straight line course to total distance swum by sturgeon (values given in %)

Region of observations	Direction of movement	Max	Min	Average		
				Females	Males	Both sexes
River Volga		52.8	6.2	33.5	19.7	23.2
Near dam zone	downstream	91.0	8.0	no differences		43.1
	upstream	79.0	3.9	no differences		33.2
Reservoir		91.0	2.6	58.6	28.0	41.6



2.2 Swimming speed

The pace during migrations upstream is dependent on the degree of complication of the zone passed by fish and on the diurnal rhythm peculiar to the species.

The sturgeon swims unrhythmically. Periods of the movement with a cruising speed of about 7.2 km/hr, lasted a maximum of 2 hours 40 min., followed by 15-40 min. intervals evidently required for a relaxation and orientation. Sharp rushes of short duration with a maximum speed of 160-180 m/min. (9.6 km/hr) often occurred after such intervals. Over a twenty-four hour period the sturgeon travelled an average 23-32 km.

The movement activity of fish in the reservoir is high on clear cloudless days. In the day-time the sturgeon move in the complicated current and bottom topography zones more confidently. Evidently visual orientation plays an essential part in spite of the near bottom living habits of the sturgeon.

In eddy zones and ones with complicated bottom relief, and if these zones are near steep or forested shores, some sturgeon after loss of orientation, prolong their circular motion, probing in different directions and pausing to determine their further course over the bottom, will jump out of the water and then swim at high speed (up to 10 km/hr) on a straight line along the coast or parallel to a dam. This phenomenon was observed repeatedly and seems to be connected with visual orientation though the mechanism of this orientation is not clear.

The maximum fluctuations found in the physical environmental conditions during the experiments were as follows: electro-conductivity 1.3 to 2.7×10^{-4} ohm $^{-1}$ cm $^{-1}$, water temperature 1-2°C, pH gradients 6.0 to 7.8 units and these changes did not cause any noticeable response in the behaviour of the sturgeon.

2.3 Response to electromagnetic disturbance

When swimming under a high-voltage electro-transmission line (110 kv) which created an electromagnetic field with horizontal strength of about 0.6 E.M.U. (Oersted) in the water, 63% of sturgeon sharply changed their courses (Fig. 3a) and all individuals slowed their pace when swimming under the overhead wires and then sharply increased it (Fig. 3b). The absence in the area of other observed factors, which could have such an influence on fish behaviour, allows us to express a hypothesis on the perception of low electromagnetic fields by sturgeon.

2.4 Response to vessels

Change in behaviour of sturgeon was repeatedly registered when they encountered vessels. The following typical response was observed: slowing down of speed to a half or a third and sometimes cessation of movement, when the vessel overhauls the fish and passes above them; a rush to one side at a speed of up to 172 m/min when the vessel approaches the fish head on. In such cases the reaction distance between fish and boat is 50-100 m. The sturgeon respond most noticeably to the noise of deepdraft twin or triple screw ships.

3 BEHAVIOUR OF BREAM DURING SUMMER MIGRATION

The courses and speeds of 93 bream were registered in different ecological zones of the Rybinsk reservoir in depths of 5-15 m in this case lightweight floats were attached to the fish, the floats being 15 g in weight with a 0.15 mm diameter line attached. The latter was fixed to the base of one ray of the dorsal fin. The courses of the fish released in both "home" areas and outside them, were traced.

All the fish tended to swim back to the region from which they had been netted. The "homewards" direction was quickly found by the fishes when they were released

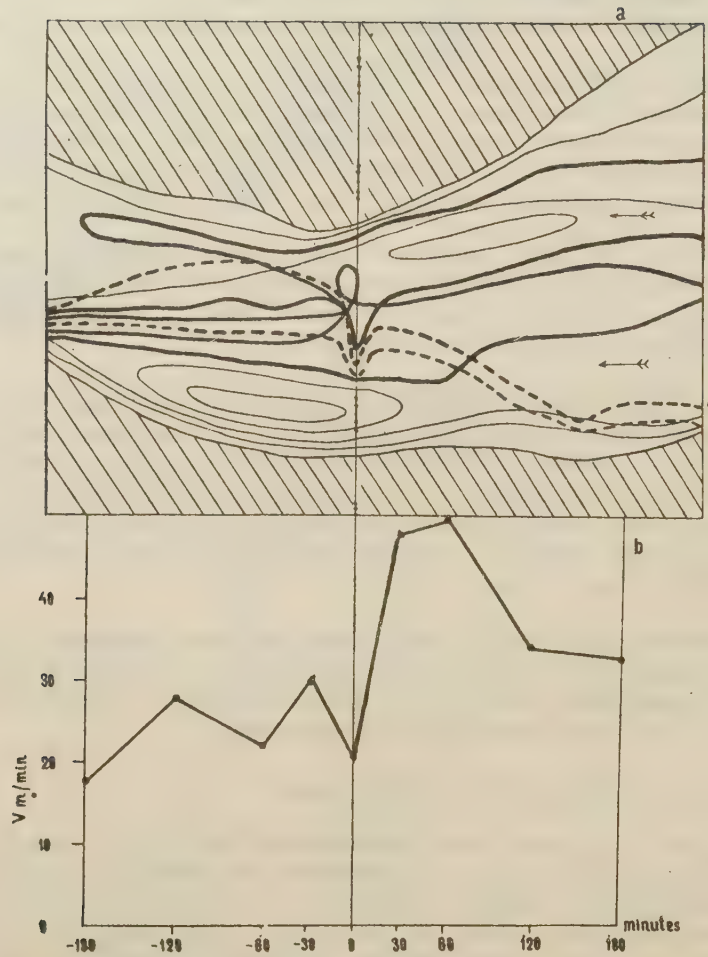


Fig. 3 Responses to electro-magnetic field alteration of the course speed changes

downstream, but the fish find their bearings more slowly in the parts of a basin where the water flow is sluggish.

A correlation was found between movement direction of the fish and bottom topography, temperature gradients and electroconductivity of the water. The water flow is as a rule crossed at an angle of 45° (Fig. 4a). When swimming in areas with no distinguishing features the bream often moves in tacks N and S (Fig. 4b). The occurrence of such a movement increases with decrease of magnitude of changes in the physical characteristics of the water mass and the depth (Table II).

Bream as well as sturgeon are apparently capable of perceiving an electromagnetic field of low intensity and using it to keep their general direction of the movement in the sections of the course where reliable marks for orientation are lacking (bottom relief changes, temperature and chemical gradients).

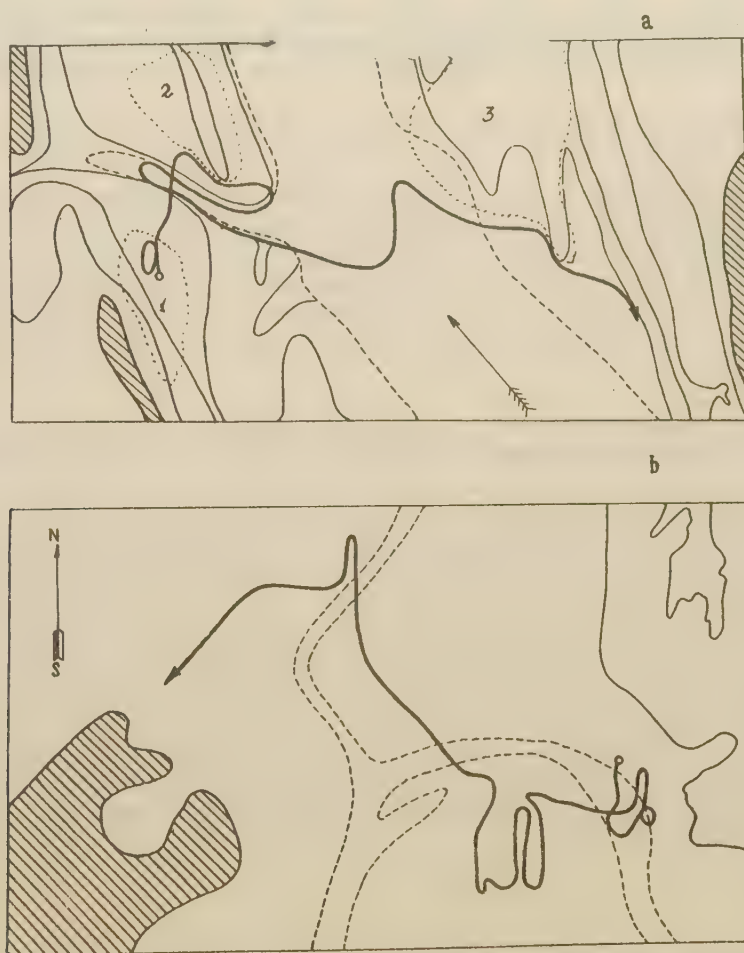


Fig. 4 Traces of bream in the reservoir

- a) release in a river reach
1-3 areas with different
temperatures and electro-
conductivity of water.
- b) release in a lake reach

TABLE II - Number of cases where bream move along the magnetic meridian

Basin Areas							
	I	II	III	IV	V	VI	
	Fluctuation Range						Units
Temperature	7.5	2.0	2.0	1.0	2.0	0.1	$^{\circ}\text{C}$
Electroconductivity	1.0	0.3	0.1	0.1	0.05	0.05	10 ohm $^{-1}$ x cm $^{-1}$
Depth	15	10	10	5	1	0.5	m
Flow	up to 20	up to 10	0	0	0	0	cm/s
Percentage cases of the movement	18	26	54	57	70	87	%

4 BEHAVIOUR OF BREAM AND BLUE BREAM IN AN AREA BOUNDED BY NETS

In different ecological zones of the reservoir the framed gillnets, 7-10 m high and 759 m length were laid out each one in a circle. Bream and blue bream tagged with common tags and floats were released inside these circles (each of 250 m diameter and 4 hectares area). The mesh size of the surrounding netting was optimum for catching that size of fish. The yield of the fish, meshed in 6, 12, 18 and 24 hours; was registered separately for the outer and inner sides of eight sectors of the net ring.

When the common tags were used, 35.2% of bream and 38.1% of blue bream became meshed (variability of the separate experiments does not exceed $\pm 5\%$).

After release in the centre of the ring the fish with their floats attached did not swim for some minutes and then they began to move along the bottom. On coming to the net about a quarter of the individuals were meshed at once, while half stopped moving at a distance of 50-100 cm from the net. The fish could stay a few hours without movement or swim slowly along the net ring, making no attempt at passing out of the ring. In 1-2 hours from the beginning of the experiment 20-25% of the fish passed the barrier in the places where the net was not too closely ajointed to the bottom, or where the floatline sagged below the surface. In an experiment at night the fish were repeatedly returned to the centre of the ring, but they again swam towards the escape way which they had found previously. Between 70 and 90% of the fish successfully left the bounded area again. Unactive individuals had filled stomachs and the fish moving in search of the outlet had not.

5 CONCLUSIONS

Distant observations on fish with sonic tags or floats attached, in the zone where fishing gears are installed, may be used for discovering and removing defects in the construction of these gears.

Recording the course and rate of movement of the fish with sonic tags, promotes the proper and well-timed installation of the fishing gears.

Investigation of fishes' natural behaviour responses dependent on environmental changes and interference factors caused in particular by the high-voltage transmission lines are worth further consideration.

6 REFERENCES

- Johnson, Y.N., Sonic tracking of adult salmon at Bonneville Dam, 1957. Fishery Bull.
1960 Fish Wildl.Serv.U.S., 60(176):471-85
- Hasler, A.D. and W.S. Wisby, The return of displaced large-mouth bass and green sunfish
1958 to a home area. Ecology, 39:289-93
- Poddubny, A.G., Some results of distant observations on the behaviour of migratory fishes.
1965 In Bionika (Bionics), Moskva, Nouka, pp. 255-63
- Poddubny, A.G., and N.A. Gordeev, The results of fishing in the open regions of the
1966 reservoirs by means of a ring shaped net. In Sbornik: Biology of fishes
of the Volga reservoirs. Moskva, Nouka, pp. 229-42
- Poddubny, A.G., U.I. Spektor and S.M. Kidum, The results of the first experiments on
1966 tracking the courence of sturgeons having the electronic tags. Vop.Ikhtiol.,
6,4(41):725-34

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THE OPTOMOTOR REACTION OF FISHES

by

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Abstract

The peculiarities of the optomotor reaction in fishes of different ecological groups in various environments are considered. The results of experiments using this reaction to direct fish movements are presented and its application to improving fishery methods are discussed.

LA REACTION OPTOMOTRICE DES POISSONS

Résumé

L'auteur examine les particularités de la réaction optomotrice des poissons de divers groupes écologiques dans différents milieux. Il présente les résultats d'expériences utilisant cette réaction du poisson pour diriger ses mouvements, et étudie les possibilités d'application au perfectionnement des méthodes de pêche.

LA REACCION OPTICOMOTORA DE LOS PECES

Extracto

Se estudian las peculiaridades de la reacción opticomotora de los peces de distintos grupos ecológicos en varios ambientes. Se presentan los resultados de los experimentos que se valen de esta reacción para dirigir los movimientos de los peces, y se examina su aplicación a la mejora de los métodos pesqueros.

1 INTRODUCTION

The optomotor reaction is usually considered as a visual locomotor reaction which is apparent by the movement of an animal after an object moves into its visual field. This unconditioned reflex reaction, intrinsic to many animals, was first described by Radl (1903). Lyon (1905) described the reaction in fishes.

The movement of a circular screen or other devices around an aquarium is often used to provoke optomotor reactions in fishes under laboratory conditions. Many authors have used the reaction to study the functional peculiarities of fish vision, their movement rates and energy. Use of the optomotor reaction is only possible after gaining a thorough knowledge of its peculiarities and its biological basis. For several years we have studied these problems and herein present a short account of the main available information.

2 THE OPTOMOTOR REACTION OF FISHES

The main condition necessary to cause an optomotor reaction is the presence of a moving visible object in the visual field of a fish. The object may be of any shape or form, e.g. a striped cloth, net webbing, various figures on paper, light patches or fish models. Hence, the optomotor reaction may be called a reflex reaction to visible objects. The number of moving objects may not be critical, but their sizes and rate of movement are of great importance, i.e. a similar reaction may be provoked by a few fast moving objects or a great many slower moving objects.

In 53 fish species studied the optomotor reaction was detected in each, with the exception of sturgeon less than 50 mm long. The reaction was most apparent in juveniles. In spite of the presence of different ecological groups represented among the fishes examined, significant differences in the distinctness of the optomotor reaction display were found only between pelagic fishes (Atherina mochon pontica Eichw, Esox lucius L., and Engraulis engrasicholus L.) and demersal fishes (Gobio gobio L., Blennius sp., Uranoscopus scaber L., and Neogobius melanostomus Pall). The reaction in representatives of the latter group was usually weaker, but it did not disappear in our experiments as it did in studies by Protasov and Altukhov (1960) and Jones (1963).

The most important condition for the emergence of an optomotor reaction is illumination (10^{-7} - 10^{-4} lux) which provides the visual perception of objects by the fishes. The distinctness of the reaction display is related, to some extent, with several physical and biotic factors. One highly significant factor is water temperature. A specific optimum range is required for maximum reaction by each species. The presence of fixed visible objects and tactile contact with the floor and sides of experimental aquaria reduced the reaction. The presence of a predator also apparently reduces, and sometimes breaks off, the reaction. Availability of food or a refuge, as a rule, apparently do not effect the optomotor reaction.

In agreement with several authors, who related the optomotor reaction to "rheotaxis" (Lyon, 1905; Schiemenz, 1927; Clausen, 1931; Protasov and Altukhov, 1960; Jones, 1963), we consider that the main adaptive importance of this reaction (both for fluvial and neritic fishes) consists in providing fishes with a means of orientation in water streams with available visible objects. Many of the peculiarities of the optomotor reaction emergence and display can be explained by reference to this biological phenomenon. In addition, several authors (Breder, 1959; Protasov and Altukhov, 1960; Shaw and Tucker 1965; Pavlov, 1965) suggest the optomotor reaction plays a significant role in the maintenance of contact within moving fish schools.

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3 EXPERIMENTAL CONTROL OF FISH MOVEMENTS WITH OPTOMOTOR REACTIONS

V.R. Protasov and J.P. Altukhov (1961) were the first to point out the possibility of using the optomotor reaction to control fish movements and thus improve the efficiency of fishing gear. In order to study applications of optomotor reactions in the control of fish movements in natural and controlled environments, a set of facilities was established.

3.1 Experiments in tanks

One of the facilities consisted of the optomotor screen (a band 28 cm high with stripes 2.5 cm wide, spaced 4 cm apart) that moved by four revolving axles along the perimeter of a rectangular tank. In another apparatus (in the same tank) screens revolved on two vertical axles placed in the middle of the tank. Following of the screen by juvenile Abramis brama L. (20 to 28 mm long) and Alburnus alburnus L. (15 to 25 mm long) was repeatedly provoked in 23 experiments. The fishes in both facilities, when reaching the corner of the revolving screen, discontinued following the screen. Distinct movements of fishes were also provoked by the movement of lighted stripes. The illusion was created with a special optomotor screen 1.5 m long, consisting of 92 waterproof lamps which were switched on alternately. In addition the movements of juvenile Leuciscus leuciscus L. (20 to 30 mm long), and Perca fluviatilis L. (28 to 30 mm long) were provoked by moving light and shadow stripes projected on a tank floor (500 x 100 x 40 cm). However, the movement of fishes in these experiments was apparent only in the middle of the tank, because the striped patterns at the sides of the tank were considerably vague.

3.2 Field experiments and observations

Screens made of net webbing with 8 to 10 mm meshes were usually used in field experiments. In the experiments on freshwater fishes the screen sizes were 200 x 27 cm, and in the experiments on sea fishes, 270 x 100 cm. A wood lath was fastened as a float to one side of the screen, and a long aluminium square or metallic rod as a weight on the other side. The screens were moved in the water with cord or by hand. Experiments on freshwater fishes, 15 to 30 mm long, were conducted in the Oka (26 experiments) and in the Volga (5 experiments) rivers. In all of the experiments with moving screens young fishes were induced to move upstream and downstream within a 150 mm distance. The number of juvenile fish following the screens ranged from several dozen to several thousand individuals, but more often one could count several hundred. The following behaviour of the juveniles was frequently observed: at first there was a fright response with the fishes moving away from the screen but subsequently some would turn and begin to follow the screen. If other fish schools occurred close to the juveniles following the screen, some fishes from these new schools, and sometimes all of them, joined the first group and began to follow the screen.

The width of the fish schools induced to follow the screen sometimes reached 1.5 m. With water transparency of 45 cm (by Secchi disc) fishes could see the screen from 30 to 40 cm, but no more. Therefore the majority of juveniles probably followed the screen without seeing it, but by imitating the fishes which could. In areas of strong wind-produced surface currents the juvenile fish did not follow upstream movements of the screen. Downstream following of the screen by juveniles stopped in the inshore plant-filled areas, where fixed plant objects disrupted the reaction.

In five field experiments juvenile Atherina mochon pontica Eichw (10 to 30 cm long) followed the screens for 10 to 60 m distances. The number of young fishes following the screens ranged from a few individuals to several hundred, but more frequently they were several dozen. Screen turnovers and the presence of fixed objects (algae, sticks, etc.) along the path of the screen had a negative effect on the optomotor reaction of

fishes during the experiments. If the rate of movement of the net webbing screen was reduced, fishes began to escape through the screen meshes and turned aside.

4 THE OPTOMOTOR REACTION OF FISHES IN RELATION TO MOVABLE FISHING GEAR

In addition to surface observation on the responses of fishes to screens, divers observed fish behaviour in relation to seine nets (60-100 m) and trawls. These observations have shown that fishes calmly travel with the seine net wings and entered the codend only when the wings were drawn close to the shore. In trawling, the majority of fishes swam parallel to the trawls' movement. It is interesting to note that some fishes which escaped over the headline continued to travel along with the trawl for several minutes. Such behaviour of fishes during trawling has been described by several authors (Vyskrebenstev, 1962; Radakov, 1964). R. Livingstone (1962) and D.V. Radakov (1964) have shown that some fishes are able to outrun and leave the trawl behind or remain in it and travel at the same speed as the trawl. In slowing down the movement rate of both the trawl and seine net, as with net webbing screens, small fishes escaped through their meshes.

To increase the efficiency of movable fishing gear the optomotor reaction of fishes being caught by them should be relaxed. The relaxation of the optomotor reaction will result in more fish entering the codends of trawls and increase their catch rates. The relaxation may be affected by minimal contrast of the fishing gear with its background. This would be easier to achieve in midwater fishing, where visible objects (stones, algae) are absent, than in demersal fishing where fixed objects are likely to break off the optomotor reaction. In bottom trawling the relaxation of the optomotor reaction may be achieved by increasing water turbidity by special otter boards.

Catches are usually inversally proportional to both water transparency and illumination, and for some fishes to water temperature. Reduced illumination reduces the visual threshold (with the absence of bioluminescence) for relaxing the optomotor reaction and catches of fish increase sharply. Increases in the catching power of both trawls (in cases where the fishes do not rise to the surface at night), and seines, with reduced illumination, are cited in the works of several authors (Mantejphel, 1961; Chestnoj, 1962). Observations made by the author in fresh and sea water from 1957-1965 confirm this phenomenon. Of course, in several cases, the relaxing of the optomotor reaction is not the only cause of increased fish yields.

5 CONCLUSIONS

All the foregoing experiments, especially those in the field, have shown the possibility of using the optomotor reaction to control fish movements for various purposes. We consider the most interesting possible application of the optomotor reaction is that of a unique method of concentrating and catching fish. Thus for example, an optomotor screen made of net webbing could be used to concentrate fish and allow them to be caught by various fishing methods. A similar principle of fishing is the bases for a little-known Viet Nam fishing method known as "luoj-mankh" (M. Anjo, 1964). As regards present fishing gear, we consider that the use of the optomotor reaction will first emerge (in principle), as a movable wing pound net.

In conclusion we should like to emphasize the necessity of conducting additional studies, with semi-commercial tests, for a better evaluation of the importance of the optomotor reaction in fisheries using moving gear, and especially to determine the possibilities of using the reaction for controlling fish movements.

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6 REFERENCES

- Ango, M., Life in tropic seas. Moskva, Izdatel'stvo Progress, 335 p.
1964
- Breder, C.M., Studies on social groupings in fishes. Bull.Am.Mus.nat.Hist.,
1959 117(6):397-481
- Chestnoi, V.N., Effects of hydrooptic factors on catching power of trawl. Trudy vses.
1962 nauchno-issled.Inst.morsk.ryb.Khoz.Okeanogr., 67:113-34
- Clausen, R.G., Orientation in fresh water fishes. Ecology., 12:541-6
1931
- Harden Jones, F.R., The reaction of fish to moving backgrounds. J.exp.Biol.,
1963 40(3):437-46
- Livingstone, Jr., R.J., Underwater television observations of haddock (Melanogrammus
1962 aeglefinus (L) in the cod-end, J.Cons.perm.int.Explor.Mer, 27(1):43-8
- Lyon, E.P., On rheotropism. 1. Rheotropism in fishes. Am.J.Physiol., 12:149-70
1909
- Manteifel, B.P., Vertical migrations of marine organisms. 2. On adaptive importance
1961 of vertical migrations of plankton-eating fishes. Trudy Inst.Morf.Zhivot.,
39:5-46
- Pavlov, D.S., The peculiarities of the optomotor reactions of fishes, In The feeding
1965 of predatory fishes and their relationships with food organisms, Moskva,
Nauka, pp:179-95
- Protasov, V.R. and Iu.P. Altukhov, Study on visual-locomotor unconditioned reflex of
1960 several fishes (optomotor reactions). Trudy karadah,nauch.Sta.T.I.
Vyazems'koho, 16:131-42
- _____, On possibility of using the optomotor reactions for management of fish
1961 movement. Ryb.Khoz., (2):29-32
- Radakov, D.V., On behaviour of several Azov Sea fishes in trawl. Vop.Ikhtiol.,
1964 4,2(31):348-53
- Radl, E., Untersuchungen über den Phototropismus der Tiere. Leipzig
1903
- Shaw, E. and A. Tucker, The optomotor reaction of schooling carangid fishes.
1965 Anim.Behav., 13(2-3):330-6
- Vyskrebentsev, B.V., Observation on fishing trawl activity on the Black Sea.
1962 Materials and results of underwater investigations. Trudy okeanogr.Kom.,
24:82-8

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MAIN TRENDS AND SOME RESULTS OF FISH BEHAVIOUR
STUDIES IN THE U.S.S.R.

by

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Abstract

Some main trends in fish behaviour studies in the U.S.S.R. are outlined. Fish reception to stimuli and its relation to the development of fishing gear and methods are discussed along with implications of conditioned reflexes and learning.

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TRAVAUX EFFECTUES EN U.R.S.S. SUR LE COMPORTEMENT
DES POISSONS: PRINCIPALES TENDANCES ET RESULTATS

Résumé

La communication expose brièvement certaines des grandes orientations des études sur le comportement des poissons menées en U.R.S.S. Elle traite de la réponse des poissons aux stimuli et des rapports entre celle-ci et la mise au point d'engins et de méthodes de pêche, ainsi que des incidences des réactions conditionnées et de l'apprentissage.

PRINCIPALES TENDENCIAS Y RESULTADOS DE LOS ESTUDIOS
SOBRE EL COMPORTAMIENTO DE LOS PECES REALIZADOS EN LA U.R.R.S.

Extracto

Se indican las principales tendencias de los estudios realizados en la U.R.R.S. sobre el comportamiento de los peces. Se examina la reacción de los peces a los estímulos y su relación con el desarrollo y modificación de los artes y métodos pesqueros, así como los efectos de los reflejos condicionados y de la experiencia adquirida por los peces.

1 INTRODUCTION

In recent years a large number of scientists have been carrying out studies on fish behaviour in the USSR. The expansion of these investigations is due to the following factors:

- (a) The growing importance of such studies in the national economy.
- (b) The establishment of several laboratories and working teams in other research and higher educational institutions for behaviour studies.
- (c) The creation of new technical means, devices and appliances for observations on fish behaviour in the natural environment and for experimental studies under various conditions both in the USSR and abroad.

The application of methods and data of different sciences (such as physics, chemistry and mathematics) has given emphasis to the quantitative aspects of fish behaviour problems. Soviet researchers combine field observations with experiments carried out in the natural and in controlled environments. When studying the behaviour of fishes we proceed from the assumption that the adaptability of each species depends on specific characteristics of orientation, signalling, structure and function of sense organs, higher nervous activities and complicated forms of behaviour. All these special features together with other adaptations enable a given population of each species to exist, i.e. to maintain its numbers at a level corresponding to given conditions. Along with studies of morphology and physiology of sense organs and nervous systems of fishes and studies of their higher nervous activities and signalling system we try to carefully clarify the ecological relations of fishes and their peculiarities. Only studies of adaptative properties of various behaviour peculiarities of different species and discovery of their mechanisms can help to lay the theoretical bases for the manipulation of fish behaviour (Manteifel and Protasov, 1963).

2 BEHAVIOUR PECULIARITIES OF FISHES

A big part of the behaviour peculiarities which differ from other characteristics of fish, and are of particular importance in biotic interrelations, include feeding, defensive, and reproductive behaviour which are extremely variable. The most important of these are food relations and defensive reactions.

In studying fish behaviour under natural conditions emphasis is being placed on a trinomial biotic relation which Manteifel (1961) calls a triotroph. When defining the importance of any factor (e.g. lighting) on changes of fish behaviour, one should never forget that besides the instant influence on the animal it could also tremendously affect the fishes biotic relations with prey, predators, specimens of the same species etc. Hence, these factors can be of the greatest importance in the conditioned reflex activity of fish.

In order to understand peculiarities in behaviour of fishes and to control their movements in desirable directions one should know the characteristic features of orientation of different species in space. Fishes use all three ways of orientation: direction finding (perception of signals from nature), location (sending signals and receiving their reflections) and signalling (sending signals by one specimen and perception of these signals by another specimen). Fishes of different ecological groups can have different functioning sets of receptors and different sense organs. Some species have a well developed complex of all main receptors (e.g. carp family). It can be said figuratively that fish are surrounded by several spheres (or fields) of action in relation to their individual receptors. The range of each of them is different. One can rather conditionally distinguish contact (sense of touch and taste) and distance receptors. The latter is also conditionally divided into receptors of short

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and distant stimuli. These are vision, hearing, lateral line and sense of smell. The peculiarities of these sense organs in many fish species are more or less known. Our knowledge of peculiarities of other receptions, such as thermoreception, receptivity to electric current and magnetic fields, etc. is far poorer.

3 DISTANCE RECEPTION IN FISHES AND ITS RELATION TO FISHING GEAR DEVELOPMENT

3.1 Visual

Fishes are not short-sighted as usually thought. With movements of the lens they can easily adjust their eyes to cover great distances. It has been noted that in clear water fishes of medium size are able to see large objects at a distance of a dozen or so meters. Small fishes of 5 to 10 cm are apt to see each other quite clearly and to distinguish other members of their school from 0.5 to 3 m. The darkness adaptation of the retina lasts about 30 min with visual thresholds increasing from 10^{-1} - 10^{-2} to 10^{-5} - 10^{-7} lux.

The reverse light adaptation takes only 10 to 30 sec. It has been ascertained that most fishes have colour vision, but the spectrum perceived by them is much narrower than that distinguished by the human eye. In sea fishes living at depths below 100 m the visible spectrum is greatly reduced to the long-wave part. In some fishes (atomus, anchovy) the frequency of glimpses merging reaches 63 to 67 whereas in humans it is only 24. Moving objects or imprints (i.e. cinema), which for human eyesight becomes one, will be perceived by such fishes as individual flashes.

Some authors have shown the relationship between lighting and processes of formation and disintegration of fish schools. This question is dealt with very thoroughly in a paper by Manteifel, Girsu, Lescheva and Pavlov (1965) who have proved that the scattering of schools, in most cases, takes place when lighting is 0.1 to 0.01 lux, whereas their formation occurs at much higher levels of illumination. Fishes have well developed visual signalling ability through poses, movements and colour changes (Protasov, Parkov and Malinin, 1966).

Vision plays an important role in different reactions of fishes which can be used for controlling their behaviour. Several researchers suggest applying the so called "reflex of following" and optomotor reaction for driving fishes into bottom set traps (Kazakovitsky, 1961) or for stimulating their passage through fish-ways. The importance of vision for orientation in water flow has to be taken into consideration when rheoreaction (rheotaxis) is to be applied (Pavlov, 1967).

Various fishes at different ages show a different reaction to artificial light. Some of them are frightened by light (e.g. most night predators) whereas others are attracted, and quite often only at certain stages of development (Girsu, 1966). Some fishes show intensive motor activity (plankton eaters, day predators) in the presence of artificial light but others (night predators) become more passive (Protasov and Robyryva, 1959). This indicates that light conditions and conditions of visual reception (e.g. turbidity) should be taken into account if one wishes to deal with a problem of controlling fish behaviour.

3.2 Sound

Recent investigations into the importance of hearing and sonic vibrations to fishes have given interesting results (Protasov, 1965). Sound signalling of fishes was studied and out of a great variety of sounds made by fishes, signals meaning threat, pain, danger, feeding, courting and so on were distinguished. Several researchers have ascertained that hearing of fishes (internal ears, the presence of which had been denied for a long time) is a distant receptor of rather long range which gives good information and helps the fish to orientate itself to some extent. It has been found

that the fish's ear is usually able to hear sounds within a wide sonic range: from 16 to 13,000 hertz on an average, with a threshold of audibility equal to approximately 0.002 bar (20-60 decibels).

The available data indicate that ultrasonic frequencies (despite statements published in some magazines) are not perceived by fishes. In recent years Soviet scientists have proved that Black Sea sprats perceive high sounds (10-15 kc/s and even higher) but only when the source strength is very great. The young of roach, perch and some other species also react to high sounds and ultra sounds (15-30 kc/s) of great intensity (5-6 wt/sq.cm) at a distance of 25-50 cm from the source. It is evident that in both cases the reaction is not caused by hearing but by pain perceived through the skin.

The ability of fishes to detect the source of sound was also disputable for a long time. It has been proved only recently. Experiments in large fish ponds at the Black Sea by Podlipalin (1962) showed that fishes of different species displayed a conditioned feeding reflex in response to the tune of a telephone receiver (quite faint). They turned toward the sound from a distance of 4 meters. At a greater distance the telephone tune was apparently inaudible to them.

A number of scientists have proved that low-frequency vibrations from 1 to 25 hertz are detected by organs in the lateral lines. In addition, the lateral line perceives hydrodynamic fields and water flows. It is suggested also that these organs are sensitive to electric field (Bodrova and Krajukhin, 1965). Hydrodynamic fields originating from small moving or vibrating objects gives rise to feeding reactions in most fishes who orientate themselves accordingly. Hydrodynamic fields originating from big objects and causing defensive reactions are detected at considerably greater distances. Predators feeding at night, in twilight or in thickets of weeds (pike, burbot and others) snap moving prey quite faultlessly by using the organs of their lateral lines.

Summing up, it can be stated that by means of the ears and lateral lines, fishes perceive sonic vibrations of a wide range (up to 13 kc/s), and from great distances. Starting from a distance of several meters (and evidently much farther) hearing in some species serves as a means of orientation. At the same time one should bear in mind that the fish's response to most sounds is usually rather passive. It is known as well that interrupted sound or sound of varying frequency and intensity affects fishes much more than permanent continuous sound. When trying to influence fish behaviour by means of sounds one should use those that give a biologically meaningful simulation. If it is necessary to scare fish one should try to simulate threatening sounds made by different fishes such as growls, drumming and chattering.

4 RESPONSES TO MULTIPLE STIMULI

It should be noted that in dealing with the problem of controlling fish behaviour it is desirable to stick to principles of combined influence on fish of several factors; at least on two or more receptors simultaneously. The influence on fish through one receptor is often unstable and not sufficiently profound. The question relating to peculiarities of higher nervous activity of fishes is also very important. A brief account of available material shows that fish behaviour of individual species is very specific and directly connected with its biology. Behaviour must be studied in relation to each species at various stages of development in specific physiological states and under defined environmental conditions. All the general laws of higher nervous activity revealed by I.P. Pavlov in relation to higher animals are applicable to fishes.

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5 CONDITIONED REFLEXES AND LEARNING

It should be taken into account that simple conditioned reflexes in most fishes appear after 3 to 25 combinations and become stable after 15 to 50 combinations (Prazdnikova, 1958). After 10 to 50 uncorroborated combinations, reflexes slow down but can renew spontaneously. Conditioned reflexes once acquired do not disappear even after a month's interruption of tests. Many fishes can acquire conditioned reflexes not only under direct influence of stimuli but also as a result of imitating fishes responding to stimuli. Such reflexes were displayed by specimens who had only watched the experiments carried out with their neighbours. This was proved by Bogomolova, Saakyan and Kozorovitsky (1958) in their tests with "actors" and "spectators". Fish "spectators" learned the things which had been taught to "actors" beyond a glass partition in the same aquarium. Moreover, there was evidence that some anchovies who developed conditioned defensive reflexes passed on this experience to other fishes when placed into a school of "untrained" fishes. When fished by hook-and-line some species develop a defensive reflex after seeing one or more specimens from their school being caught. After fading away, this reflex was immediately restored when fishing was resumed.

Such "training" is obviously of great significance and direct concern for the biological understanding of the schooling behaviour of fish. The subject is dealt with quite thoroughly in a special paper by D.V. Radakov presented to this Conference; therefore it will not be considered here at length.

6 CONCLUSION

In a short report it is impossible to outline all the theoretical assumptions from which Soviet researchers proceed in their studies of fish behaviour, and to describe the results of these investigations. Therefore, in conclusion we wish to emphasize the necessity of furthering and expanding studies of fish behaviour along the following lines:

- (a) To reveal the adaptive meaning of peculiarities in fish behaviour.
- (b) To study reception, orientation and signalling of fishes as mechanisms for maintaining the processes of behaviour reactions.
- (c) To work out biological bases to control fish behaviour for the rational utilization of fish resources through the development of improved fishing gear and methods.

7 REFERENCES

- Bogomilova, E.M., S.A. Saakian and L.B. Kozarovitskii, Imitative conditioned reflexes
1958 in fishes. Trudy Soveshch. ikhtiol. Kom., (8):51-4
- Bodrova, N.V. and B.V. Krajukhin, The lateral line of fishes as apparatus for perceiv-
1965 ing electric field. Moskva, Bionika Nauka Publishing House
- Kazarovitskii, L.B., Reflexes of following of some fish species. In Summaries and
1961 results of papers. Third scientific meeting on evolution physiology
convened in commemoration of Academician L.A. Orbeli
- Manteifel, B.P. and V.P. Protasov, The role of physics in studying fish behaviour.
1963 Problemy Ikhtiol., 3(3):28
- Manteifel, B.P., et al., The influence of varying lighting on formation and scattering
1965 of fish shoals. In Feeding of predatory fishes and their relations with
food organisms, Moskva, Nauka, pp. 82-90

- Pavlov, D.S., Optomotor reaction and orientation of fishes in water flow and some
1967 problems arising in connection with construction of fish ways and fish
protectors. Moscow
- Podlipalin Iu. D., Ability of some Black Sea fishes to orientate themselves towards
1962 the sound source. Problemy Ikhtiolog., 2(4):25
- Protasov, V.P., Bioacoustics of fishes. Moskva, Nauka Publishing House, 20 p.
1965
- Protasov, V.P., A.A. Darkov and L.K. Malinin, Visual images in discerning and signal-
1966 ling of fishes. Izv.Akad.Nauk SSSR (biol.), (1):59-75
- Prazdnikova, N.V., Study of the activity of the central nervous system of fishes,
1958 using the food-conditioned motor reflex method. Trudy Soveshch.ikhtiolog.
Kom., (8):31-7 (Repr. from Trudy Soveshch.Fiziol.Ryb., 1956)

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SOME PECULIARITIES OF TRAWLING TECHNIQUE APPLIED IN FISHING FOR
BERING SEA REDFISH DEPENDING ON ITS BEHAVIOUR AND ENVIRONMENT

by

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Abstract

As from 1960 the commercial fleet commenced the exploitation of redfish in the Bering Sea. Starting with a variety of trawl types, the ineffective gears were eliminated within the period of one year. The narrow width of the schools strung along an isobath and their varying proximity to the bottom enforced the devising of new trawling tactics and search procedures.

PARTICULARITES D'UNE TECHNIQUE DE CHALUTAGE EMPLOYEE POUR LA PECHE DU SEBASTE
DE LA MER DE BERING EN RAISON DE SON COMPORTEMENT ET DU MILIEU

Résumé

C'est en 1960 que la flotte de pêche commerciale a entrepris l'exploitation du sébaste dans la mer de Béring. Les opérations ont commencé avec divers types de chaluts, les engins donnant de mauvais résultats ayant été écartés au bout d'un an. Les bancs de sébastes sont étroits et s'échelonnent le long d'un isobathe à des distances variées du fond; aussi a-t-il fallu mettre au point des tactiques de chalutage et des méthodes de prospection nouvelles.

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CARACTERÍSTICAS DE LAS TÉCNICAS DE PESCA DE ARRASTRE
EN EL MAR DE BERING A LA CAPTURA DE LA GALLINETA
SEGÚN SU COMPORTAMIENTO Y AMBIENTE

Extracto

La explotación comercial de la gallineta en el mar de Bering se inició en 1960. De los diversos artes con que se comenzó, los que no dieron buenos resultados se eliminaron en menos de un año. Por ser estrechos los cardúmenes que se encuentran a lo largo de una isobata y por variar la proximidad a que están del fondo, obligó a idear nuevos métodos de arrastre y procedimientos de búsqueda.

1 INTRODUCTION

In 1960 the trawl fishing for various species of redfish (Pacific Ocean perch, Alaska perch, rockfish and sea bass) started in the Bering Sea. Neither behaviour of redfish nor how best to fish it were known at that time. Therefore the first two years of the redfish fishery were in essence a period of determining the most efficient construction of a redfish trawl and finding an optimum regime and rational methods for its operation.

Special investigations during the fishing seasons, taking due account of redfish behaviour and the conditions of its habitat, made it possible that by the end of 1962 the trawling technique became established, and later this technique with certain modifications was applied on almost all trawlers operated in that area.

2 TRAWLING DEPTH FOR REDFISH

Bering Sea redfish does not form large concentrations. It is found in individual, comparatively small schools: usually 300 to 500 m in length and 15 to 20 m in height. Sometimes the thickness of schools reaches 60 to 80 m. Schools over 50 m in the width are met with rather seldom. As a result, trawling back over the same course is not often successful, because a slight shift of course or of the school is sufficient for the school to be missed.

The isolation and narrowness of redfish schools are the main reasons why fishing vessels cannot obtain stable catches over the 24 h period. Their trawls are hauled aboard sometimes full and sometimes empty. In order to avoid this, the chart of trawl positions throughout the cruise is plotted during actual fishing operations with indications of the course and duration of trawling and with notes on the most suitable resultant depths.

In summer redfish is distributed within a layer from 130 to 350 m, but the range of depth where individual schools are found is not wide. If there are schools, say at a depth of 130 to 150 m, then as a rule they cannot be found in the same area at depths of 150 to 200 m, but can occur again for instance at 200 to 250 m, and again disappear within the layer from 250 to 300 m.

In order to secure efficient trawling, the operations are carried out along "catchable" isobaths. When trawling it is important not to allow the trawl to descend more than 50 m below the initial depth.

Up to mid-May the redfish schools do not usually leave the sea bed. The lower (5 to 8 m) of the schools are more dense than their upper portion. Such a structure of schools dictates the minimum vertical opening of trawls which will secure good catches. During the first year of operations trawls of all types available in the Far East area were applied in this redfish fishery. By the second year only those trawls which had a vertical opening not less than 5 to 8 m remained in use.

At the end of May redfish schools start to be found at 10 to 15 m off the bottom. Sometimes in June the schools occur within a layer 50 to 90 m above the bottom in depths of 140 to 350 m. Such schools do not provide a commercial catch for, when in the water column, redfish become more dispersed and enter the trawl as individual specimens.

3 SPEED AND NET RIGGING CONSIDERATIONS

Redfish is often caught in netting pockets, flaps and walls which are at an angle to the trawl's movement. Very often redfish do not pass into the cod-end; but it is meshed in wings, bunt or square because of the asymmetry of the trawl when towed. This mostly happens when the trawler turns round or when warps are of uneven lengths.

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To prevent the possibility of capturing redfish in wings or bunt it is necessary to avoid turning with trawl; trawling is effected along a straight course. Warps are paid out very carefully so that the trawl net should not be distorted because of difference in their length. The captures of redfish in wings, bunt and square decrease considerably if trawling speed is increased from 2.5 to 4 kn.

When trawling speed goes down to 2.5 to 2 kn. the catch becomes poorer, and the proportion of fishes, which do not pass into the cod-end, increases. At the time of hauling the trawl (and, more precisely, at the moment of its leaving the bottom) redfish start to move out of the cod-end.

If the trawl when heaving does not make headway through the water equivalent to its towing speed, then by the time the otterboards approach the side of the vessel, redfish is already found in the square and even beyond it. In this case not all the catch comes aboard: part of it remains in the square and another part escapes from the trawl altogether.

The presence of redfish in areas with rough bottom makes it necessary to rig the trawl in such a manner as to minimise its contact with the sea bed so that ground-rope or chains attached to the footrope hardly touch the bottom. The footrope itself can be placed up to 1 m above the ground.

If this distance is bigger the catches decrease whereas catches decline sharply when connection with bottom is lost completely, i.e. when neither footrope nor groundrope nor chains touch the bottom. Most often the redfish trawl net is fitted so that its footrope is about 1 m above the sea bed. But sometimes such a well-adjusted trawl will stop taking commercial catches.

The observations show that this is connected with changes in configuration of the schools (such as broadening and mainly decreasing of their dense part down to only 1 to 3 m). In this case chains have to be shortened so that the footrope is only 20 to 30 cm from the bottom or even touching the ground. Up to 1961 in the Far East area trawling operations were carried out in the traditional way, i.e. the trawler found an appropriate isobath, lowered the trawl net and towed it along that isobath for 1 to 1.5 h more or less blindly. If catches provided to be very big, the duration of trawling was shortened.

4 A NEW TACTIC

In 1960 the vessels equipped with echo sounders and fish detectors were able to locate bottom and off-bottom schools of red fish. They conducted trawling along a chosen isobath until a school was encountered and then they towed through the school. Since in 1960 the redfish schools were met frequently, the whole duration of trawling did not, as a rule exceed 45 to 60 min.

In 1961 the frequency of occurrence of redfish schools dropped sharply and dimensions of discovered schools were much less than previously. Consequently, simply trawling along an isobath with fishfinding apparatus in action became ineffective. Despite prolonging the trawling time up to 1.5 to 2 h the number of empty hauls was still greatly increased on the previous year. Due to longer tows more frequent trawl damage also occurred.

In this situation commercial vessels equipped with fishfinding devices were forced to change their trawling tactics; they started with hydro-acoustic searches for schools. After having detected a school of redfish, the trawler lowered its trawl net manoeuvring in such a manner that before warps were fixed in the towing block the vessel was on course and fishing of a school started. Duration of trawling depended on the size of the school. Since the redfish schools are rather narrow, the trawlers still sometimes failed to position the net to fish the detected school.

This gave rise to another trawling tactic now tested in practice. The trawler moves along the isobath slowly towing a trawl net at 25 to 30 m above bottom. When a school is detected the warps are quickly released, the trawl net sinks to the bottom very quickly and the trawler tows the net through the school without changing its course. The trawl-net once passed through the school is hauled aboard.

When the warps were being released the speed of the trawler goes up to nearly full speed and after finishing the veering of the warps the speed again becomes reduced to normal.

One of the advantages of this method is that the probability of tearing the trawl net on the ground is considerably reduced and the accuracy of positioning the net on to the school is much higher. A special towing block is, however, necessary to reduce wear and tear.

The trawl sinks rapidly to the bottom when warps are released. By means of TAG (a special bathymeter intended for measuring the depth of submersion of a fishing gear or any of its parts) the time "landing" of the trawl on the sea bed was defined. The records of TAG showed that a capron herring trawl of 27.1 m long fitted with 35 to 45 hydrodynamic floats, pieces of chains weighing 40 to 50 kg in total and 3 m² oval shaped boards with original length of warps equal to 400 to 450 m sank at a rate of 25 to 30 m per minute.

Several fishing vessels employed yet another tactic of trawling which differed from the above in the manner of shooting the trawl net.

The trawler moves along the isobath in search of fish schools with a trawl net towed off the bottom at the highest possible speed. When a fish school is detected, the trawler continues moving without changing its course but reducing the speed to the lowest limit. The trawl sinks to the bottom without additional release of warps. It is towed through the detected school and eventually hauled aboard the vessel which does not leave the location of a school. The average rate of settling here is considerably less than when using the second method. Searching power of the vessel is, however, increased because of the higher towing speed when searching.

The experimental measurements made from the fishing trawler OGON showed that if this last tactic is adopted and the trawling speed is reduced from the highest (5.15kn) to the lowest (3 kn) limit the rate of settling down of the net is 15.9 m per minute.

When the vessel's speed changed from maximum to medium (4.4 kn) the rate of sinking was 11.3 m per minute. Thus the last tactic of trawling requires more time for settling a trawl net on the bottom and consequently it is more difficult to avoid the net passing above the school if the latter is small.

5 REFERENCES

- Lestev, A.V., New tactics in Far East ocean perch fishery. Ryb.Khoz., 38(7):6
1962
- _____, Some problems of catchability and damaging of trawl nets in fishing for
1963 redfish. Izv.tikhookean.nauchno-issled.Inst.ryb.Khoz.Okeanogr., 49:8
- _____, Trawling technique in Ocean Perch fishery in the Bering Sea. Trudy
1964 vses.nauchno-issled.Inst.morsk.ryb.Khoz.Okeanogr., 53:15

ON THE NEGATIVE RESPONSE OF POLAR COD
(Boreogadus saida Lepechin) TO ELECTRIC LIGHTS

by

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Abstract

Investigations on the responses of Polar cod to electric lights were conducted at sea. The fish reacted to illumination at mid-depths by rapid movements toward the bottom. The use of their negative response in a method of trawling is described.

REPONSE NEGATIVE DE LA MORUE POLAIRE (Boreogadus saida Lepechin)
DEVANT LA LUMIERE ELECTRIQUE

Résumé

Des études ont été effectuées en mer sur les réactions de la morue polaire en présence de lampes électriques. Devant des lampes placées entre deux eaux, le poisson a réagi par un déplacement rapide vers le fond. L'auteur décrit un procédé permettant de tirer parti de cette réponse lors du chalutage.

SOBRE LA REACCION NEGATIVA DEL BACALAO POLAR
(Boreogadus saida Lepechin) ANTE LAS LUCES ELECTRICAS

Extracto

Se investigaron en el mar las reacciones del bacalao polar ante las luces eléctricas. A profundidades medias los peces reaccionaban dirigiéndose rápidamente hacia el fondo. Se describe el empleo de esta reacción negativa en un método de pesca al arrastre.

1 INTRODUCTION

Investigations carried out by the Polar Institute (PINRO) of the USSR showed that almost yearly, in autumn and winter, pre-spawning and spawning concentrations of Polar cod are observed in the eastern and northern areas of the Barents Sea (Ponomarenko, 1961, 1963, 1964). Norwegian investigators have also observed these concentrations at various depths during autumn. With the aid of underwater photography they were able to verify that these fish were Polar cod (Midttun and Saetersdal, 1959). The schools have been recorded with echo sounders both near the surface of the sea and over the whole water column down to the bottom (Ponomarenko, 1966). Judging from recordings, these concentrations are not dense in the water column and near the bottom they are registered above the level of the vertical mouth opening of a bottom trawl (Fig. 1). Thus, in spite of good indications, catches did not exceed 300 to 500 kg per haul (Ponomarenko, Natenzon and Naumov, 1962). Repeated attempts to fish these concentrations with different gear were not satisfactory.

D.V. Radakov (1965) stated that in spite of effective techniques for catching fish developed during centuries of fishing experience and through modern investigations on the methods of fishing, it is not always possible to successfully catch fishes found under certain circumstances. This is frequently due to the fact that schooling offers a certain amount of protection (Nikolsky, 1955). Even bottom fishes form schools, just as pelagic fishes, when they meet trawls (Jonas, 1960). Judging from our observations on Polar cod, pelagic fishes migrate downward when frightened by fishing gear and if depths are not sufficient they press against the bottom. Finding themselves between the otter boards of a trawl, fishes probably concentrate between the cables and when a groundrope approaches move upward to escape the gear but frequently end up in the net.

2 RESPONSES TO LIGHT

Studies on adult Polar cod (those with an accelerated growth rate of gonads) during October to December (Ponomarenko, 1965a) have indicated a negative response to underwater electric lights. The experiments were conducted on the fishing grounds and catches consisted entirely of pre-spawning Polar cod. Sizes and other biological data of these fishes are given in Table I.

Experiments with electric illumination showed that a switched-off lamp sinking into a school did not cause excessive scattering. When the electric light was turned on, recordings of Polar cod on the echo sounder disappeared immediately. Figure 2 shows that the concentration of Polar cod did not respond to the sinking lamp but disappeared the moment the light was switched on. While the light was on there were traces of Polar cod on the bottom. After the light had been turned off, the fish left the bottom and returned to their original position in the water column (Fig. 3).

When the light was switched on the echo sounder did not record the sinking of the fish to the bottom but their upward movement was distinctly registered when the light was switched off. Echo-sounder records showed that the fish moved much more rapidly when the light was turned on than when they returned to their normal level after the light was turned off. We therefore see that Polar cod respond to electric lights at mid-depths by rapid movements toward the bottom followed by gradual movements upward in the water column after the light has passed. It is thus possible to use this negative response of Polar cod to light while fishing for them with a bottom trawl. To obtain this response, lights were incorporated into a method of trawling (Ponomarenko, 1965b), as shown in Fig. 4. It is possible that luminescent hydrodynamic floats, instead of electric lights, could be used to concentrate Polar cod in the path of a trawl. Certainly there are other possible techniques of using electric lights for catching Polar cod.

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Fig. 1 Recording of Polar cod with the echo sounder HAG-240 on board the SRT BALAKLAVA north-east of the Kolguev Island in October 1960



Fig. 2 Recordings of concentrations of Polar cod showing their disappearance during periods of illumination

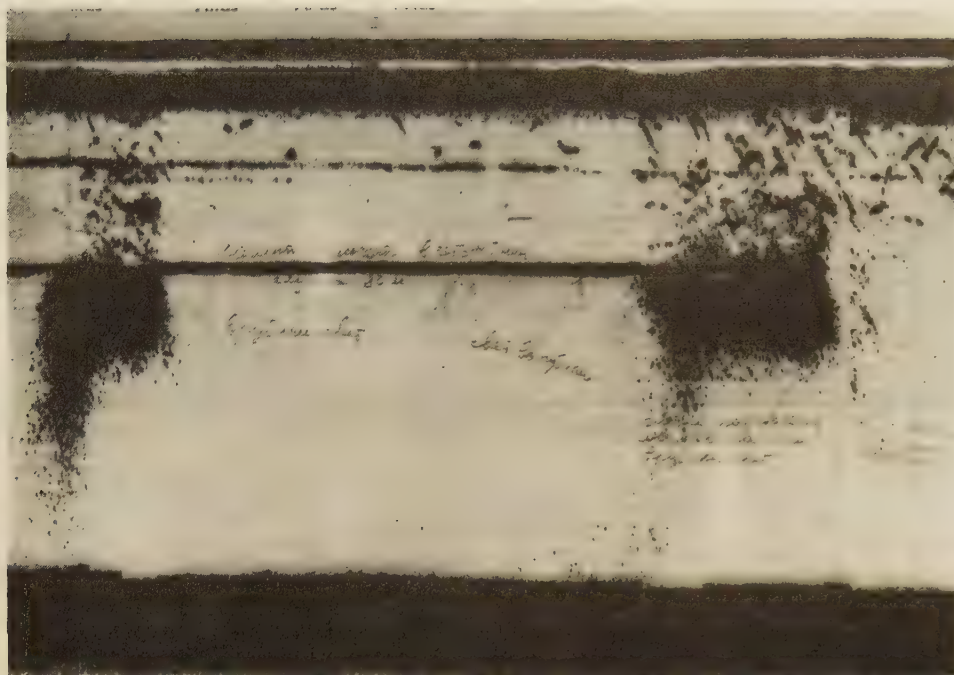


Fig. 3 Recording showing concentrations of Polar cod moving up in the water column after switching off the light

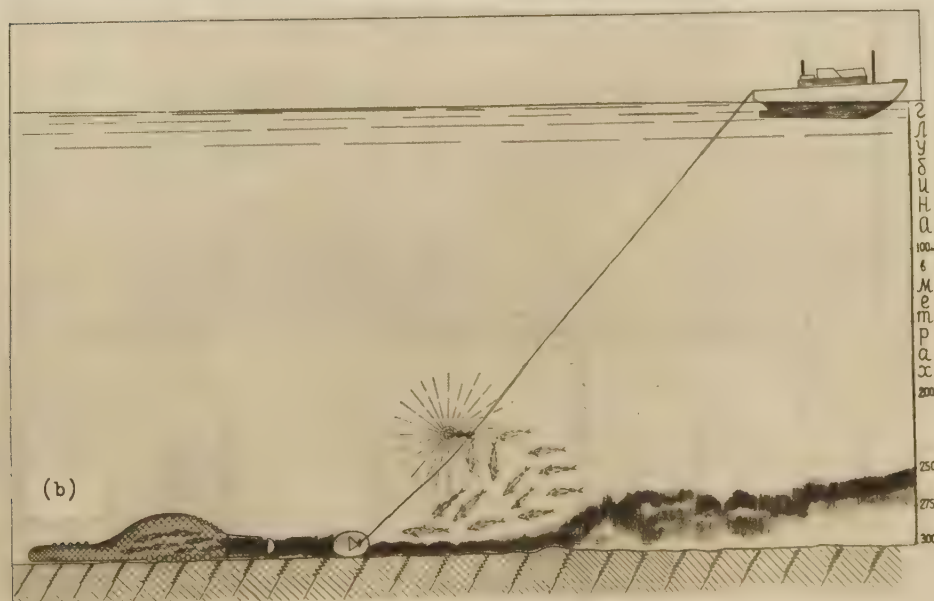
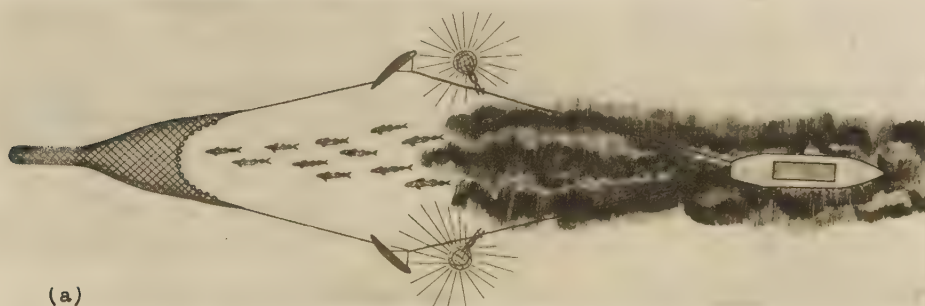


TABLE I - Sizes and other data on pre-spawning Polar cod caught during light experiments

Sex	Length in cm										Total Number
	16-17	17-18	18-19	19-20	20-21	21-22	22-23	23-24	24-25		
	Length-frequency by individuals										
Females	2	5	5	11	12	7	2	2	1	47	
Males	-	6	16	14	26	10	3	1	-	76	
Males and Females	2	11	21	25	38	17	5	3	1	123	
	Index of sexual maturity, in %										
Females	2.5	3.5	3.6	3.8	2.7	4.8	5.3	-	-	29	
Males	-	14.0	11.5	11.3	10.8	15.6	10.7	10.2	-	42	
	Weight of liver, in % of the body weight										
Females	8.4	10.7	11.0	10.2	8.9	6.0	9.8	-	-	29	
Males	-	9.5	7.8	8.4	7.3	9.5	8.3	7.0	-	42	
	Average weight in g										
Females	29	36	38	44	45	49	61	74	75	47	
Males	-	36	38	43	48	57	59	72	-	76	
Males and Females	29	36	38	43	47	54	60	74	75	123	

3 REFERENCES

- Jonas, V.A., Investigation on the behaviour of sculpin in the area of a bottom trawl
1960 operations. Ryb.Khoz., 2:35-9
- Middtun, L. and G. Saetersdal, Forsök med undervanns-kamera. Fiskets Gang, (28):415-9
1959
- Nikolskii, G.V., On the biological significance of shoals in fishes. Trudy Soveshch.
1955 Vop.Poved.Razved.Ryb, 5:104-7
- Ponomarenko, V.P., Distribution of Polar cod in the autumn-winter period in the
1961 Barents Sea. ICES, C.M.Gadoid Fish Committee, (78):7 p.
- _____, Autumn and winter distribution of pre-spawning and spawning concentra-
1963 tions of Polar cod (Boreogadus saida Lepechin) in the Barents Sea. Trudy
poliar.nauchno-issled.Inst.morsk.ryb.Khoz.Okeanogr., 15:177-97
- _____, Areas and conditions of Polar cod spawning in the Barents Sea. In
1964 Materialy sessii Uchenogo soveta PINRO po rezul'tatam issledovaniy v 1962-
1963, Murmansk, vol.3:220-6
- _____, The development of gonads and terms of Polar cod spawning in the Barents
1965(a) Sea. Dokl.Akad.Nauk SSSR, 161(3):697-700
- _____, On techniques of Polar cod fishing. Ryb.Khoz., 6:44-6
1965(b)
- _____, Some data on the distribution and migration of Polar cod (Boreogadus
1966 saida Lepechin) in the seas of the Soviet Arctic. ICES, C.M.Symposium
on the Ecology of Pelagic Fish Species in Arctic waters, (15):9 p.
- Ponomarenko, V.P., Kh. M. Natenzon and V.M. Naumov, Experimental cruise on Polar cod
1962 fishing. Ryb.Khoz., 12:36-40
- Radakov, D.V., Studying of fish behaviour while fishing. Vop.Ikhtiolog., 6:37-46
1956

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BEHAVIOUR OF FISH IN THE ZONE OF THE LIGHT
USED IN THE CASPIAN KILKA FISHERY

by

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3 EFFECT OF CURRENT ANGLE	835
4 LAMP DISTANCE	836

Abstract

Describes the use of a row of electric lights for attracting Caspian kilka. An attempt is made to express in precise terms the relationship between the properties of the source of light and the quantity of fish gathered.

PECHERIE DE "KILKAS" (SPRATS) DE LA MER CASPIENNE:
COMPOTEMENT DU POISSON EN LUMIERE ARTIFICIELLE

Résumé

L'auteur décrit l'utilisation d'une rangée de lampes électriques pour attirer les "kilkas" (sprats) de la mer Caspienne. Il s'efforce d'exprimer de manière précise le rapport entre caractéristiques de la source lumineuse et la quantité de poissons rassemblés.

EL COMPORTAMIENTO DE LOS PECES EN LA ZONA DE LA LUZ
EMPLEADA EN LA PESCA DE KILKA DEL MAR CASPIO

Extracto

Describe el empleo de una serie de luces eléctricas para atraer la "kilka" del Mar Caspio. Trata de expresar en términos precisos la relación existente entre las propiedades de la fuente de la luz y la cantidad de peces capturadas.

1 INTRODUCTION

In the modern fishery catching fish or other organisms with the use of light has developed noticeably in many countries. In the future, this kind of fishery will undoubtedly receive further attention, not only as an independent method, but probably in connection with other factors influencing fish (electric current, sound taste, etc). In all cases it is important to improve the methods which artificially increase the concentration of fishes in the zone of fishing gear. One of the ways of increasing the fishing effect is the use of light traces.

The use of light traces for fishing the Caspian kilka (*Clupeonella* spp.) by pumping is of the greatest practical interest, for in this case it is very important to provide a continuous flow of the fish to the catching zone of the group. An interesting use of light traces during kilka-fishing arose some time ago. The first experiments in this direction were carried out in 1955, but gave no positive results, for they were performed without taking into consideration many peculiarities of attraction and behaviour of kilka in the light traces's zone of actions. It was thought that during the night kilka does not move actively, and remains in passive condition drifting with the current. It is known from fishing practice, that during certain hours of the day herring does not move actively and seldom enters drift nets. It is best caught during the evening and morning hours, when it is feeding and, consequently, actively moving. A sharp increase of the catch by 2 to 3 times is also observed in the fishing of Caspian kilka during a period of 15 to 20 min before sunrise.

2 FISH ATTRACTION TO A LIGHT TRACE

Let us again return to the peculiarities of attraction of kilka into the lighted zone. As the path of its drift meets the lighted zone the kilka's activity increases and it is attracted to the source of light (Fig. 1). The part of the school that has not fallen into the lighted zone, naturally, continues its drift.

It should be mentioned that in the case of a strong current which exceeds the speed of the fish's locomotion, there is no concentration of fish near the light source. It was observed that kilka failed to concentrate near a light source if the speed of the current is 0.35-0.40 m/sec. In such cases fishermen change the region of fishing and try to work in areas of calmer waters.

The use of a light trace envisages (Fig. 2) that by successive switching of the five lamps in a definite interval of time "t" (beginning from the extreme lamp No. 5) it will be possible little by little to lead the fish up to the light source (lamp No.1) installed at the end of the pump.

Let us count the quantity of fish which it will be possible to collect by the end, near lamp No. 1. Assuming that the light sources (F) are all of equal light flows, their gathering ability (Q), all other conditions being equal will be proportional to the time of their action (t), that is to say

$$Q \propto F \cdot t$$

In this dependence the time of action of each lamp will be a variable value. Let us find out the whole time of shining of all the lamps in the light trace with successive switching over during 1 cycle of their work. This time naturally depends on the number of lamps (n), composing the light trace. Initially all lamps are employed. After t units of time lamp N is switched off. Thus the nth lamp is on for a time

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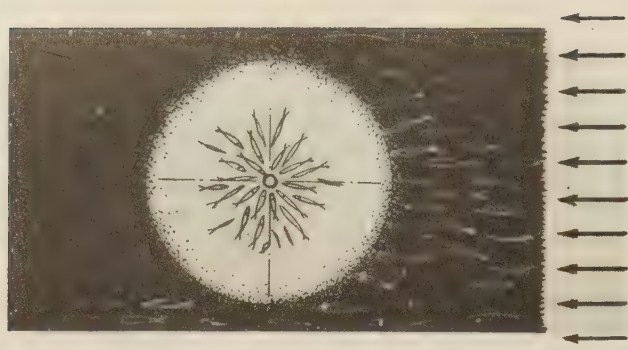


Fig. 1 Model of fish attraction by artificial light

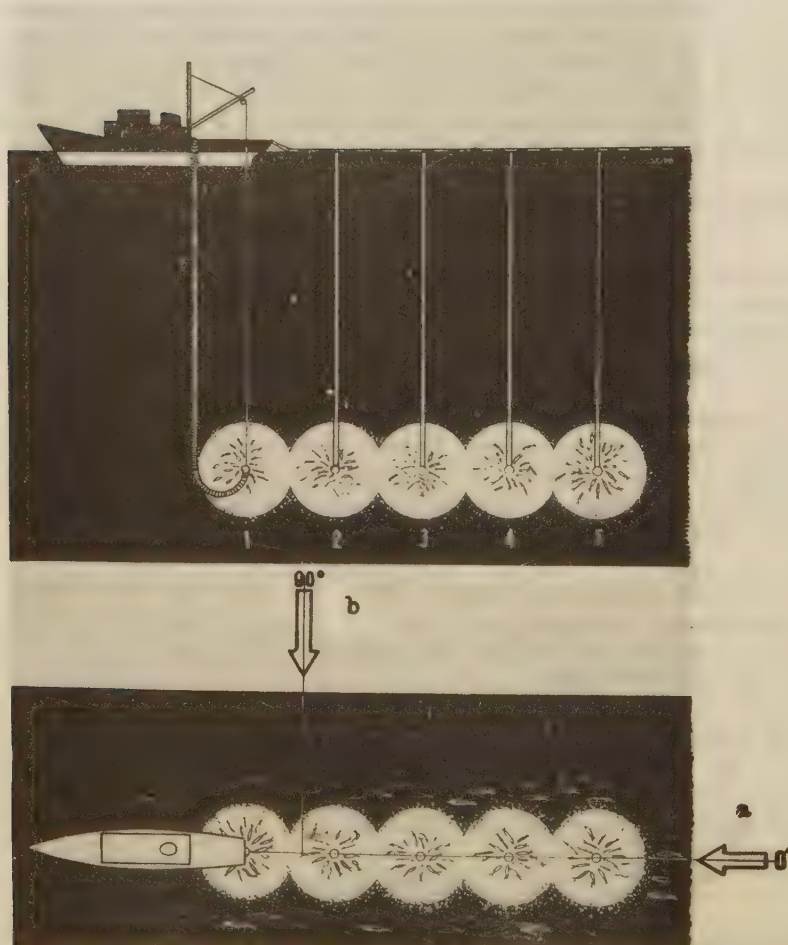


Fig. 2 Light trace. a. Drift of fish parallel to the light trace ($\alpha = 0^\circ$); b. Drift of fish perpendicular to the light trace ($\alpha = 90^\circ$)

$t_n = tn$. After $2t$ units of time the $(n-1)$ th lamp is switched off. This lamp is on for $t_{n-1} = 2t$ units of time. The first lamp will be on for $t_1 = n-t$ units of time. Thus the total time of shining is given by:

$$\sum_{i=1}^n t_i = t(1+2+\dots+n)$$

$$= t \frac{1}{2} n(n+1)$$

Let us define the coefficient of increase of the concentration of fish during one cycle as the ratio of the total time or of the trace to the total time or of one lamp shining continuously during this same cycle. Denoting this coefficient by C we have:

$$C = \frac{\sum_{i=1}^n t_i}{nt} = \frac{\frac{t}{2} (n+1)}{nt} = \frac{n+1}{2}$$

When $n = 5$ $C = 3$ and
 When $n = 10$ $C = 5.5$

Thus, the use of light trace of 5 lamps theoretically increases the concentration of fishes near the source of the light (lamp No. 1) by 3 times and using the trace, consisting of 10 lamps, by 5.5 times. However, this theoretical effect is only attained when the trace is oriented to the current and hence the drift of the fish in an optimum manner.

3 EFFECT OF CURRENT ANGLE

Let us consider two extreme cases (Fig. 2) when the light trace is situated parallel to the current $\alpha = 0^\circ$ and when it is perpendicular to it $\alpha = 90^\circ$.

In the first case (Fig. 2a) the fish drifts and comes into the light zone of lamp No. 5 where it concentrates. When it is turned off the fish moves to lamp No. 4 and thus by turning off successive lights the fish is led up to the first source, where it is pumped. In this case there is no effect of the light trace, for only lamps attract fish effectively; the rest could have been achieved by drift.

Let us observe the second case (Fig. 2b). Let us imagine that the direction of the current (fish's drift) has changed and it became perpendicular to the direction of the light trace. In this case each lamp of light trace will attract the fish and the successive switching of the lamps will give us quite definite advantageous effect.

On the basis of the facts, declared by the author, the comparative tests on the effectiveness of light trace's work during pumping of Caspian kilka were performed. The traces were situated in one case at an angle of 72° to the current; in the other, under the angle of 0° . The installation of the trace was performed from the ship, taking into account the direction of the current and its strength. Fishing was performed at the depth of 20 m where the current's speed was 0.26 m/sec.

The trace consisted of 3 lamps, each of strength 1.5 kw, their successive switching over was conducted 1.5 min. The distance between the first lamp and the second was 10 m, and between the second and the third 6.3 m. When the trace was parallel to the current the catch was only 27% of that obtained when the trace was at an angle of 72° to the current. Thus, the experiments bore out the importance of the correct orientating of the light trace to the current.

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4 LAMP DISTANCE

When using a light trace, it is necessary to take into consideration that the conditions of switching over the lamps, their number and distance between need not be constant, but can be altered according to the species of the fish, its concentration, and to different factors of the environment and biological condition of the fishing object too.

The distance between the lamps (L) must be enough to let light fields cover each other. This condition is satisfied when

$$L = \frac{R}{1.5} \quad \text{where } R \text{ is radius of attraction.}$$

The dependance is given:

$$B = \frac{F}{4 R^2} \cdot e^{-\gamma R}$$

taking logarithms, where:

e = 2,7 the base of natural logarithm

E = the light at which the fish is attracted to light source

γ = coefficient of total weakening of light

F = light intensity

The time of switching over (t) should be enough to let the fish pass the distance (L) from one lamp to another. The number of lamps in the light trace will be determined by the value of concentration of fish in this region of fishery. The higher the concentration is, the lower number of lamps should be present in the light trace.

The practical use of light trace will demand an adequate light supply (lamps, cables). It is also suggested that construction of two-side traces will increase twice the efficiency of this type of gear. Before installing the light trace it is necessary to have data on speed and direction of the current, and to check them during fishing. All this, of course, makes the work of a ship with light trace more difficult, but at the same time promises great commercial effect.

* * * * *

THE BIOLOGICAL AND PRACTICAL IMPORTANCE OF
SCHOOLING BEHAVIOUR IN FISHES

by

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Abstract

The adaptive significance and mechanisms of fish schooling behaviour and their application to the improvement of fishing gear and methods are discussed. Some general theoretical concepts are briefly reviewed.

IMPORTANCE BIOLOGIQUE ET PRATIQUE DE LA FORMATION DES BANCS DE POISSONS

Résumé

L'auteur examine la signification, du point de vue de l'adaptation, et les mécanismes du comportement des poissons en matière de formation de bancs, ainsi que les possibilités de les utiliser pour perfectionner les engins et méthodes de pêche. Il passe brièvement en revue certaines notions théoriques d'ordre général.

IMPORTANCIA BIOLOGICA Y PRACTICA DEL COMPORTAMIENTO
DE PECES AL FORMAR CARDUMENES

Extracto

Menciona el autor la importancia de la adaptación, los factores que influyen en el comportamiento de peces que forman cardúmenes, y su aplicación a la mejora de los equipos y métodos de pesca. Reseña sucintamente algunos conceptos teóricos generales.

1 INTRODUCTION

We concern ourselves in this paper with certain regularities of schooling behaviour which are related to the task of controlling behaviour to increase the catching power of fishing gear, or improving the efficiency of fishing methods. We especially emphasize the necessity to produce maximum yields with guaranteed continuous reproduction of stocks of fishes. In other words we are approaching the problems of how to get maximum sustainable yields without violating the principles of sound fishery management. Sufficiently developed and flexible fishing technology must be in compliance with fishery management.

In order to use the regularities of schooling behaviour of fishes for the development of fishing gear and fishing methods it is first necessary to know these regularities. Some proposed theoretical concepts of this work are presented and may help in future studies. We suggest that the exchange of information on the theory of schooling behaviour is as useful as the exchange of practical data. Studies on the regularities of schooling behaviour should help to clear up the following problems:

- (a) What does the adaptive significance of a fish school imply.
- (b) What are the mechanisms which determine the pattern of a fish school.

Any adaptation is relative: it is adaptation under certain conditions (Vasnetzov, 1953). For example different spines and fins may protect some fish species from predators but these spines may place the fish in an extremely dangerous position when they are near fishing nets (Marty, 1961). Furthermore, when in some circumstances schooling is not to the fishes' advantage, the school disintegrates and the fish scatter. We find that even though there is enough light for fish to see each other scattering occurs. Thus, in the evening at lower illumination when it is easier for predators to locate a school than a solitary individual, many schooling species scatter. (Manteifel *et al.*, 1965). Scattering at low light intensities becomes a protective mechanism for each fish.

A fish school, in our opinion is a temporary community of fishes of a single species (generally) similar in physical and physiological make up, which are related in their behaviour and have similar adaptive responses. In addition, the significant feature of a fish school is coordination of actions which they display or can display at any time.

2 ADAPTIVE SIGNIFICANCE OF FISH SCHOOLING

A fish school possesses adaptivity at least in the following conditions:

1. in protection against predators
2. in search and capture of prey
3. in spawning
4. in wintering
5. in migration and locomotion (Manteifel and Radakov, 1960)

In a mathematical calculation of defense, schooling decreases the possibility of meeting with predators (Brock and Riffenburgh, 1960; Orfeev, 1963; Olson, 1964). By inter-school signalling an entire fish school can avoid danger even if it is detected by only a part of the school, e.g., the whole school may escape from fishing gear through a hole in the net located by a single or a few individuals. Finally, 1) multiplicity and mobility of fish in a school, 2) special protective manoeuvres such as the large numbers of fish moving in many directions simultaneously and, 3) the space that is created around a predator as it moves into the school with the fish going in the opposite direction to the predator by them

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results in disorientation of a predator, thus making capture unlikely. Aquarium experiments showed that a cod spent an average of about 26 sec to capture a solitary saithe yearling, while the capture of its first fish in a school took 5 times longer. Often a predator fails to catch fish from a school and even gives up after unsuccessful attacks (Radakov, 1958, 1961). Usually predators catch solitary preys, which have strayed from schools (Taranenko, 1955); Manteifel and Radakov, 1960; Eibl-Eibesfeldt, 1962, and many others). Schools frequently respond to a predator by dividing, passing on opposite sides of the predator, and re-grouping in his rear. This is a highly effective and successful means of predator avoidance (Manteifel and Radakov, 1960). One can observe this manoeuvre when sufficiently large bodies (including some fishing gear or their component parts) penetrate a fish school.

In search of food, schooling permits the whole school to gather food even when it is found by only a part of the school. Thus juveniles of saithe (Pollachius virens L.) gathered ground food in an aquaria in a short time even though some individuals of the school did not see it, originally. Some of them located the food by imitating the movements of fishes which saw it (Radakov, 1958). When hunting, the schools of predatory species can surround prey, preventing their escape (Steinman, 1951; Eibl-Eibesfeldt, 1962). Furthermore, the schooling behaviour of predatory fishes often makes it possible for them to scatter a prey school and hence catch individuals separately. Besides, a school of predatory fishes can frequently force prey out of their usual shelters or "press" them to the surface, whence the capture is easier. (Eibl-Eibesfeldt, 1962; Radakov, 1965). Finally, predators which hunt in schools can disorientate their prey and make them more available for capture.

Experiments showed that catches of juvenile saithe by a trap in a big aquarium considerably increases if predators such as cod are present (Radakov and Nikolaev, 1959). Fish "learning" in schools is of great importance to both fishery biology and fishery development. Thus cultured young which do not gain enough conditioned defensive reflexes are destroyed by predators at a greater rate after release than those grown in the natural environment (Popov, 1953). There are data showing that fishes "learn" to avoid certain types of fishing gear. Due to a high degree of imitation in schooling fishes, learning seems to be of great significance.

3 SOME "MECHANISMS" OF SCHOOLING BEHAVIOUR AND THEIR APPLICATION TO FISHERY DEVELOPMENT

It is very important to learn how to control the movement of fish schools. For a successful fishery one must learn how to make fish move in a certain direction towards this or that fishing gear or, on the contrary, to retain a school at some point while the gear is approaching it.

Experiments show that attempts to induce fish to move in a definite direction with the help of any frightening stimulus usually result in the formation of "dents" on the surface of a school, in the formation of a space without fish and/or a "vacuum", inside the school (in relation to the position of the frightening stimulus). Hence it does not cause any re-direction or stoppage of the school as a whole. This is explained by the fact that the following responses are intrinsic to fish in danger:

- (a) They make a quick rush, but for only a short distance.
- (b) They escape from danger by curving around the place where the frightening stimulus is located rather than in a straight line.

To control the whole school's movement it is necessary to understand and to use the laws that govern the behaviour of fish in schools. These laws predict the distribution of waves of movement and the interference of the waves with each other (Radakov, 1966).

The results of our observations and experiments with both sea and freshwater fish schools showed that when a single frightening stimulus was used on the majority of fish schools one could observe a latent period - i.e. time between initiation of the stimulus and the locomotor reaction of the fish, together with a zone of direct fish response - i.e. where all fishes responded to the stimulus simultaneously, and an external zone - i.e. where fishes responded not to the frightening stimulus itself but to the behaviour of other fishes. The above causes a "wave of movement" in a school where fish perform progressive movements. In some cases a "flurry of activity" (Breder, 1959) covers an external zone. Fishes involved in such "flurries" sharply curve their bodies, then again straighten them without progressive movement. According to our data the swimming speed of single individuals of Atherinomorus stipes is approximately 10 times slower than the distribution of a "flurry of activity" in a school.

Grouped fishes tend to attenuate the "waves of movement". Hence the school is a kind of "silencer" of these waves. There are also waves of movements which increase or expand with time. They may emerge in schools in the following cases:

- (a) When an attractive stimulus is in effect. Under these conditions there arises a "chain reaction" in the waves of movement. As a rule in such a school a "vacuum" or space never has time to occur and a wave spreads like an avalanche.
- (b) "Waves of movement" may be stimulated and may act as an attractant to the remainder of the school. For example, when a frightening stimulus is applied to one part of the school that part moves quickly. The rest of the school flows into the frightened part and a second wave of movement occurs, a wave which is not attenuated but spreads into the other part.

Schooling behaviour in fishes is a form of adaptation to ensure the existence of the species under given conditions. The biological importance of schooling behaviour in fishes is great, and the several regularities of schooling behaviour in fishes, including "mechanisms" for transmission of information within a school, may be effectively used for controlling the movement of fish schools for future development of fishing gear and fishing methods.

4 REFERENCES

- Breder, C.M., Studies on social groupings in fishes. Bull.Am.Mus.nat.Hist., 1959, 117(6):397-481
- Brock, V.E. and R.H. Riffenburgh, Fish schooling: a possible factor in reduction predation. 1960 J.Cons.perm.int.Explor.Mer, 25(3):307-17
- Eibl-Eibesfeldt, J., Freiwasserbeobachtungen zur Deutung des Schwarm verhaltens verschiedenen Fische. Z.Tierpsychol., 19(2):165-82
- Manteifel, B.P. and D.V. Radakov, On studies of adaptive significance of schooling behaviour in fishes. Usp.sovrem.Biol., 50(36):362-70
- Manteifel, B.P., et al., The influence of changing illumination on formation and scatter of schools in fish. In The feeding of predatory fishes and their relationships with food organisms, Moskva, Nauka, pp. 82-90

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- Marty, Y.Y., Contradiction of some protective features of fish in nature and fishing.
1961 ICES, Comparative Fishing Committee, 1-3
- Olson, F.C.W., The survival value of fish schooling. J.Cons.perm.int.Explor.Mer,
1964 25(3):115-6
- Orfeev, Iu.V., On an adaptive role of schooling behaviour. Dokl.Akad.Nauk SSSR,
1963 152(4):995-7
- Popov, G.V., Materials on studying defensive conditional reflexes in fry of fish.
1953 Zh.vyssn.nerv.Deiat.I.P.Pavlova, 3(5):774-88
- Radakov, D.V., On an adaptive significance of schooling behaviour of young saithe
1958 (Pollachius virens L). Vop.Ikhtiolog., 11:69-74
- _____, Some peculiarities in defensive behaviour of schools of some pelagic fish
1961 Trudy Inst.Morf.Zhivot., 39:47-71
- _____, The significance of schooling for predatory fishes on capturing the prey.
1965 In Feeding of predatory fishes and their relationship to food organisms,
Moskva, Nauka, pp. 173-8
- _____, On a peculiarity of schooling behaviour in fishes. ICES, Comparative
1966 Fishing Committee (F4):5 p.
- Radakov, D.V., and D.S. Nickolaev, The attitude of young saithe to moving trap net
1959 (tests in the aquarium). Zool.Zh., 38(7):1103-5
- Steinmann, P., Fischeschwärme und was die bedeuten können. Schweiz.FischZtg., 6
1951
- Taranenko, N.F., Some peculiarities of anchovy behaviour in the Black Sea as effected by
1955 predators and some fishing gears. Trudy azov.-chernomorsk.nauch.rybokhoz.Sta.,
16:89-98
- Vasnetzov, V.V. Ecological integrity of fish species. In Papers on the General problems
1953 of ichthyology. Moskva, Izdatelstvo Akad. Nauk SSSR, pp. 91-117
- Welty, J.C., Experiments in group behaviour of fishes; a study of the influences of the group
1934 on individual behaviour. Physiol.Zool., 7(1):85-128

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UNDERWATER OBSERVATIONS ON THE BEHAVIOUR OF FISHES IN
THE ZONE OF TRAWLING

by

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Abstract

The method of direct underwater observations has been employed to study the reaction of fish to bottom and pelagic trawls in the Black Sea and to a mechanized goby seine in the Azov Sea. The escape of fish in the fishing zone of the bottom trawl was observed. During studies of the function of the pelagic trawl it was observed that schools of horse mackerel were following the trawl from outside which could be explained by optomotor reaction. Vigorous movements of captured fish were observed in the posterior part of the codend during towing.

OBSERVATIONS SOUS-MARINES SUR LE COMPORTEMENT
DES POISSONS DANS LA ZONE DE CHALUTAGE

Résumé

L'observation sous-marine directe a été employée pour étudier le comportement du poisson devant les chaluts de fond et les chaluts pélagiques dans la Mer Noire, ainsi que devant une seine à gobie manœuvrée mécaniquement dans la Mer d'Azov. On constate que le poisson fuit la zone de pêche du chalut de fond. Au cours d'études sur le fonctionnement du chalut pélagique, on a observé que des bancs de chinchards suivaient le chalut de l'extérieur, ce qui s'explique peut-être par des réactions optomotrices. Les poissons se trouvant dans la partie postérieure du cul de chalut manifestent une vive agitation pendant le traînage.

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OBSERVACIONES SUBMARINAS SOBRE EL COMPORTAMIENTO
DE LOS PECES EN LAS ZONAS DE LA PESCA AL ARRASTRE

Extracto

El método de la observación submarina directa se ha empleado para estudiar las reacciones de los peces a las redes de arrastre de fondo y pelágicas en el Mar Negro y a una red de cerco mecanizada para pescar chanquetes en el Mar de Azof. Se observó la fuga de los peces en la zona en que actúa la red de fondo. Durante los estudios realizados sobre el funcionamiento de la red de arrastre pelágica se observó que cardúmenes de jureles seguían a la red desde fuera, hecho que puede explicarse por una reacción optomotora. Durante el remolque, se observaron vigorosos movimientos de los peces capturados en la parte posterior del copo.

1 INTRODUCTION

The investigation of behaviour of fishes in the action zone of fishing gear is essential for understanding the function of the gear and making recommendations for its improvement. For this purpose direct underwater observations are important.

The work reported here was carried out during August to September 1966, in the Black and Azov Seas. Divers with aqualungs used the method described by Vyskrebentzev (1962). They descended with the trawl holding onto the headline, or a rope attached to the headline, with a safety boat following closely. This work was conducted by research workers of the VNIRO Laboratory for underwater investigations aided by sport divers.

2 BOTTOM TRAWL

Studies of fish behaviour were made chiefly on the greater weaver, Trachinus draco; the skate, Raja clavata; the ray, Dasyatis pastinaca; and the flounder, Scophthalmus maximus. The underwater observations confirmed the herding effect of the mud-stripe caused by otter boards (Vyskrebentzev, 1962; Martyshevskii, 1965).

The reaction of demersal non-schooling fishes in front of the trawl was as follows: when a part of the trawl (board, cable, wing) or the mud-stripe came as close as 0.5 to 2 m, the fish swam away at speeds up to 1 m/sec. The direction in which the fish swam varied in a spread up to 120°. The reaction speed of the fish continued until it was 1 to 3 m from the trawl. Some fish showed a "jumping" reaction up to a metre from the bottom. Once the fish got beyond the 1 to 3 m proximity of the trawl or mud-stripe, it swam at its regular speed until the trawl came close again. This could occur a number of times before the groundrope caught up with the fish.

Since the visibility was more than 5 to 7 m, the fish apparently was reacting to a disturbance which reached a critical level well within the visual range.

The fish's reaction to the groundrope is different from its reaction to front parts of the trawl. In the latter case, the fish can recede in three possible directions whereas in the former, the fish usually swims in only one direction. When the groundrope is within 1 to 2 m, the fish turns so that its head is pointed in the direction of the approaching trawl and therefore the fish swims into the trawl.

When swimming in front of the groundrope, the fish usually keeps ahead of the line by 0.3 to 1.5 m and for a while maintains a speed similar to that of the trawl. The fishes in front of the groundrope may divide into several layers depending on the concentration of fishes. They maintain a uniform speed without sharp jerks. Larger fishes periodically approach the bottom line seeking a way out and, if the clearance below is large enough, some escape. In contrast, smaller fishes (weavers, gobies) swim steadily ahead and seldom try to escape under the groundrope.

When the fish are in only one layer, 0.1 to 0.3 m above the bottom, they usually do not attempt to escape under the bottom line even when it is raised a little from the bottom.

The behaviour of fishes near the groundrope is one of the most important factors in the catchability of bottom trawls. Our observations show the importance of eliminating the clearance under the groundrope and also between the edge of the net and the groundrope. Even small clearances of a few centimeters can sharply reduce the catchability of a trawl.

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A fish trapped in front of the net can speed up several times to keep away from the approaching net but eventually it tires and slips back into the codend. Here, there is generally an outburst of activity as the netting touches the fish and they rush about, often from one wall to the other. Eventually these erratic swimming movements also slow down and the fish in the codend swim in the direction of trawling for a short time or are pressed into the netting by the flow of water.

3 MIDWATER TRAWLS

The most interesting and unusual observation made on the 30 m trawl was a mass movement of horse mackerel outside the trawl. Radakov (1964), and High and Lusz (1966) noticed individual fish and even small schools of fish attracted to the netting outside of a moving trawl. Our observations show that this phenomenon can be massive.

In some cases, horse mackerel swam over the upper side of the trawl and entered the trawl (Fig. 1). In other cases they came to the lateral sides of the trawl and small schools entered through the large mesh in the wing part of the trawl. In at least half the cases observed, we can eliminate the possibility of an "imitation" reflex (these schooling fish attempting to join others in the net) as the horse mackerel within the trawl were beyond the vision of those swimming above the trawl.

We therefore conclude that horse mackerel swimming in the area outside and above the netting did so as a result of an optomotor reaction (visual orientation to the moving net) also discussed by Altukhov and Protasov (1960) and Pavlov (1965).

We also made observations on horse mackerel inside the trawl. Some actively entered the trawl through the space between the wings. They swam along the outside of the codend to the critical area in front of the trawl where they turned into the trawl and kept pace with the trawl's speed. It is doubtful that their behaviour, once inside the trawl, is largely optomotor but probably depends on other stimuli as well (e.g. approach of netting, sound, etc.).

4 THE MECHANICAL GOBY DRAGNET

Observations were made on the reactions of two species of gobies (Gobius fluviatilis and Gobius melanostomus) in relation to moving dragnets. The drag ropes caused a cloud of mud for a distance of 25 to 30 cm. Usually the gobies occurred in small groups of 2 to 10 rather than as isolated specimens. Although groups of gobies seldom swim together naturally at a uniform speed, their reactions to the dragnet are school-like in character. They accumulate in front, mainly near the groundrope and react in two ways. A "bottom" group can escape under the dragnet when there is clearance and some outside were seen to follow the net. When the groundrope is tight against the bottom, gobies in the "bottom" group swim in front for a while, go out of the dragnet under it, fall behind into the net, or join the second or "swimming" group. This later group is the second main supply of gobies caught in the dragnet.

Some gobies were able to swim rapidly forward and upward out of the dragnet zone. Usually these gobies came from the rear of the swimming group, nearest the net. In the front part of the codend both the bottom and the swimming groups formed homogeneous aggregations. If some fishes slow down, they can form a provisional swimming group which may continue for 10 to 15 sec after which the gobies are deeper in the dragnet. When the gobies touch the net, the typical burst of activity and erratic swimming follows before the gobies are pressed into the posterior part of the codend by water flow.

During the period of chaotic swimming, when the water appears to be boiling, some gobies accidentally or intentionally break through the netting aided by the strong flow of water, even through small holes where only one mesh is torn.

The difference in behaviour of fishes in different parts of fishing gear shows up as important in trawling operations. Even a large opening in the middle of a dragnet did not necessarily cause gobies to withdraw.



Fig. 1 Horse mackerel entering the mouth of the midwater trawl

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5 REFERENCES

- Altukhov, M.P. and V.R. Protasov, On the visual reactions of some fishes to moving
1960 nets. Ryb.Khoz., 36(4):9-11
- High, W.L. and L.D. Lusz, Underwater observations on fish in an off bottom trawl.
1966 J.Fish.Res.Bd Can., 23(1):153-4
- Martyshevskii, V.N., The effect of the eddy trails of the otterboards on the catching
1965 ability of the trawls. Ryb.Khoz., 41(12):28-30. Also issued as Transl.
Fish.Lab., Lowestoft, (80):5 p.
- Pavlov, D.S., Characteristics of optomotor reactions of fishes. In The feeding of
1965 predatory fishes and their relationships with food organisms, Moskva,
Nauka, pp. 179-93
- Radakov, D.V., On the behaviour of some Azov fishes in trawl. Vop.Ikhtiolog., 4,2(31):
1964 348-53
- Vyskrebentzev, B.V., Observations on the action of trawls in the Black Sea. Materials
1962 and results of underwater investigations. Trudy okeanogr.Kom., 14:82-9

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AUDITORY THRESHOLDS OF THE SCOMBRID FISH
Euthynnus affinis, WITH COMMENTS ON THE
 USE OF SOUND IN TUNA FISHING

by

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Abstract

A threshold curve for acoustic sound pressure showed that Euthynnus affinis perceived sounds from 100 to 1,100 Hz. For the two fish tested the lowest mean threshold determination was 7 db/1 microbar at 500 Hz. The threshold was 30 db/1 microbar higher at 100 Hz. than at 500 Hz., and was 23 db/1 microbar higher at 1,100 Hz. than at 500 Hz. Mean thresholds for E. affinis were consistently higher than those previously obtained for another scombrid, the yellowfin tuna (Thunnus albacares). This difference may have resulted in part from the lack of a swim bladder in E. affinis; however, the role of the swim bladder in tuna hearing has not been precisely determined. The difference may also be related to greater flow noise generated by E. affinis, which typically swam faster than yellowfin tuna. More intense flow noise could cause the fish to require louder incoming sounds for detection. The most successful way that sound can be used in tuna fishing is probably to repel or control the fish with intense sounds. Frequencies between about 300 and 700 Hz. should be chosen but the required sound levels may be most readily determined through trial and error experiments. High-frequency fish-finding sonars probably do not have an adverse effect on tuna behaviour or physiology.

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SEUILS AUDITIFS DU SCOMBRIDÉ Euthynnus affinis,
ET COMMENTAIRES SUR L'UTILISATION DU SON DANS LA PÊCHE AU THON

Résumé

Sur la base de la courbe du seuil d'audibilité (pression sonore) Euthynnus affinis perçoit les sons dont la fréquence s'étage entre 100 et 1.100 Hz. Pour les deux poissons ayant fait l'objet de l'expérience, la plus basse valeur moyenne de seuil obtenue était de 7 dB (réf. 1 barye) à 500 Hz. Le seuil était plus élevé de 30 dB (réf. 1 barye) à 100 Hz qu'à 500 Hz, et de 23 dB à 1.100 Hz qu'à 500 Hz. Pour E. affinis, les seuils moyens étaient régulièrement plus hauts que ceux qui avaient été relevés auparavant pour un autre Scombridé: l'albacore (Thunnus albacares). Cette différence peut provenir en partie de l'absence d'une vessie gazeuse chez E. affinis quoiqu'on n'ait pas déterminé avec précision le rôle de cet organe dans l'audition des thons. Il se peut aussi que la différence soit liée au bruit de déplacement, plus élevé chez E. affinis, dont la nage est plus rapide que celle de l'albacore. Avec un bruit de déplacement plus fort, il se peut que l'animal détecte seulement les sons d'intensité supérieure. Pour employer le son au mieux dans la pêche du thon, il faudrait probablement avoir recours à des sons de grande intensité pour éloigner ou diriger le poisson. Les fréquences devraient être dans la bande 300 - 700 Hz, mais c'est par tâtonnement que l'on pourra le mieux déterminer les niveaux sonores nécessaires. Les sonars détecteurs de poissons à haute fréquence n'ont probablement aucun effet défavorable sur le comportement ou la physiologie des thons.

UMBRALES AUDITORIOS DEL PEZ ESCOMBRIDO Euthynnus affinis,
CON COMENTARIOS SOBRE EL USO DEL SONIDO
EN LA PESQUERIA DE ATUN

Extracto

Una curva del umbral de la intensidad de los sonidos acústicos mostró que Euthynnus affinis los percibía desde 100 a 1.100 Hz. Con respecto a los dos peces probados, la determinación del umbral medio más bajo fue de 7 db/1 microbara a 500 Hz. El umbral fue 30 db/1 microbara más elevado a 1.100 Hz que a 500 Hz. Los umbrales medios para el E. affinis fueron mucho más altos que los obtenidos previamente para otro escombrideo el rabil o atún de aleta amarilla (Thunnus albacares). Esta diferencia puede deberse, en parte, a que E. affinis carece de vejiga natatoria; sin embargo, no se ha determinado con precisión la función que desempeña ésta en el sentido auditivo del atún. La diferencia puede relacionarse también con el mayor ruido que produce E. affinis, que generalmente nada más velozmente que el rabil. Un ruido más intenso al nadar podría hacer que para localizar al pez se necesitará incrementar la intensidad del sonido emitido por el detector. El mejor modo de valerse del sonido en la pesca del atún consiste, probablemente, en alejar o controlar a los peces con sonidos intensos. Se deben elegir frecuencias comprendidas entre 300 y 700 Hz, pero el modo más rápido para determinar los niveles de los sonidos necesarios consiste en experimentar. El empleo de sonar de alta frecuencia para localizar peces probablemente no ejerce consecuencias adversas en el comportamiento o en la fisiología del atún.

1 INTRODUCTION

An increasing world-wide demand for fish is reflected by steadily rising catches of tuna and by increased efforts to develop new fishing methods and tactics for their capture. One approach to improving fishing tactics is to make use of information on the behaviour of tuna, particularly on their ability to detect various external stimuli. Underwater sounds are among the most ubiquitous stimuli in the tunas' environment; hence the ability of the fish to detect these sounds, and the effect of these sounds on them should be considered in developing new fishing tactics.

The purpose of this report is to describe hearing thresholds and frequencies audible to E. affinis, compare the auditory responses of the fish with those of yellowfin tuna, and comment on possible implications of their hearing abilities on fishing. The experiments were carried out at the tuna behaviour facility, U.S. Bureau of Commercial Fisheries Biological Laboratory, Honolulu, Hawaii, U.S.A.

Previous research on hearing in tunas has been mainly concerned with their ability to detect sounds; less work has been performed to determine the behavioural effect of sounds on tuna. Miyake (1952) attempted to attract or repel yellowfin tuna (Thunnus albacares (= Neothunnus macropterus) and also Euthynnus affinis^{1/} (= E. yaito) with continuous sounds from 100 Hz.^{2/} to 70,000 Hz. but achieved no positive results. Iversen (1967) conditioned two free-swimming yellowfin tuna in a large holding tank to respond to underwater sounds from 50 to 1,100 Hz. and obtained hearing thresholds over that range. Speculative or anecdotal comments on the use of sound to guide tuna or on the meaning of sound to tuna have been made by several workers. McNeely (1961) described several uses of sound that are thought to prevent tuna from escaping a purse seine. Timofeev (1965 and personal communication) noted that production of sounds called "knocks" by skipjack tuna (Katsuwonus pelamis) occurred at the same time as vertical changes in the swimming depth of the school. Iversen (1967) suggests that sounds probably made by musculoskeletal action of the yellowfin tuna during rapid body flexes could be used for communication between fish.

2 EXPERIMENTAL PROCEDURES

Data were collected from two E. affinis (44 and 54 cm fork length) during May and June 1966, and November 1966, through January 1967. Both were captured and transported to the experimental tank by the method described by Nakamura (1962). The experimental tank was 7.2 m in diameter and 1.2 m deep and was acoustically insulated with a 38-mm thick mat of rubberized pig and horse bristles. Details of the equipment used to produce and measure the sounds, background noise levels in the tank, variations in the sound field near the transducer, and the method of conducting the experiments are given by Iversen (1967). However, a brief description of the training and experimental procedures follows.

^{1/} Because of lack of agreement on the common name of this species, I shall refer to it simply as Euthynnus affinis. It has been variously called little tunny, little tuna, wavyback skipjack, and (in Hawaii) kawakawa.

^{2/} 1 Hertz (Hz.) = 1 cycle per second (c.p.s.).

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The E. affinis was first conditioned to associate a 500 Hz. sound projected from the underwater transducer (J-9, Chesapeake Instrument Corp.^{3/}) with a food reward. After a few days of training the fish turned sharply towards the food reward area each time it perceived the sound while swimming past the transducer. The fish was next trained to swim past the transducer at a specified distance and to either (1) turn left through a passageway formed by two nets if a sound was projected from the transducer, or (2) swim straight ahead through another passageway formed by two nets if no sound was projected. Thus each time the E. affinis swam past the transducer it had to decide to turn left or swim straight ahead. Choice of the wrong swimming pathway was counted as an error.

The stimulus was projected during the interval the tuna swam over a rectangular marker 18 x 64 cm placed on the bottom of the tank about 36 cm from the transducer. Sounds were usually generated with a Hewlett Packard 2AB audio oscillator, but occasionally were generated with an RCA-44B audio oscillator.

Threshold levels were determined by use of a modification of the method of limits (Andreas, 1960), in which the level of the stimulus was reduced by a standard amount (5 db) after each group of 20 trials until the fish no longer responded. A Hewlett Packard model 350D attenuator was used to reduce the signal. The sound level during any group of 20 trials that included 10 in which the fish chose the wrong swimming path (50 percent error level) was considered to be below its threshold. Threshold was then defined as a level halfway to the previous level tested.

Two types of hydrophones were used to measure sound levels - a Clevite CH-15 oyster hydrophone with a frequency response flat from 50 to 2,000 Hz., and an Atlantic Research Corporation LC-54 hydrophone with a frequency response flat from 1 to 30,000 Hz. The hydrophones were coupled to a sound-level meter (General Radio model 1551-C) in place of the meter's air microphone. A correction factor was added to the decibel level shown on the sound-level meter to compensate for the difference in sensitivity between the hydrophones and the air microphone normally used with this meter.

The sound level at threshold was determined after testing with the hydrophone in the position of the tuna during actual trials. First, the stimulus was transmitted with zero attenuation and measured with the sound-level meter. Next, the amount of attenuation, in decibels, required to bring the E. affinis to the 50 percent error level was subtracted from the corrected sound-level meter reading.

Higher sound-pressure levels were required for responses by E. affinis than by yellowfin tuna. To prevent over driving of the electronic equipment and possibly distorting the test frequency, and introducing undesired frequencies into the water, the E. affinis was trained to swim closer to the underwater transducer than the yellowfin tuna. This distance was about 36 cm compared with about 50 cm for the yellowfin tuna.

It was estimated the E. affinis swam past the transducer 25 to 50 percent faster than the yellowfin tuna, apparently because it must swim faster than yellowfin tuna to generate the lift necessary to keep from sinking (Magnuson, 1966).

Decibel values in this report are rounded off to the nearest whole number. Unless otherwise stated, decibel values are given in reference to 1 microbar (1 dyne/cm^2) as the 0 db level.

^{3/}Trade names referred to in this publication do not imply endorsement of commercial products.

3 RESPONSE OF Euthynnus affinis TO SOUND

A threshold curve for acoustic sound pressure based on data from the two E. affinis is shown in Fig. 1. The curve was fitted to the data by the least squares method for a polynomial. Thresholds were obtained from 100 Hz. to 1,100 Hz.; the lowest mean determination (7 db) was obtained at 500 Hz. Thresholds at either end of the curve were much higher. The threshold was 30 db higher at 100 Hz. than at 500 Hz., and was 23 db higher at 1,100 Hz. than at 500 Hz.

The greatest difference between the two fish was at 700 Hz., where the mean thresholds were 5 db and 19 db. A difference of 14 db between the two individuals is not uncommon. For example, Tavalga and Wodinsky (1965) reported differences this great at 700 Hz. between individual bluestriped grunts (Haemulon sciurus), and even greater differences at other frequencies.

The range of variability in single-threshold determinations at a given frequency was usually 10 db or less, but one fish had a maximum range of 15 db between thresholds at 500 Hz. On some occasions ranges greater than 10 db may have been caused by the E. affinis swimming closer to the transducer than expected. When deviations from the desired swimming path were obvious, experiments were halted for the day. Less obvious deviations may have caused the E. affinis to perceive a sound close to threshold that it would not have perceived had it been slightly farther away from the transducer.

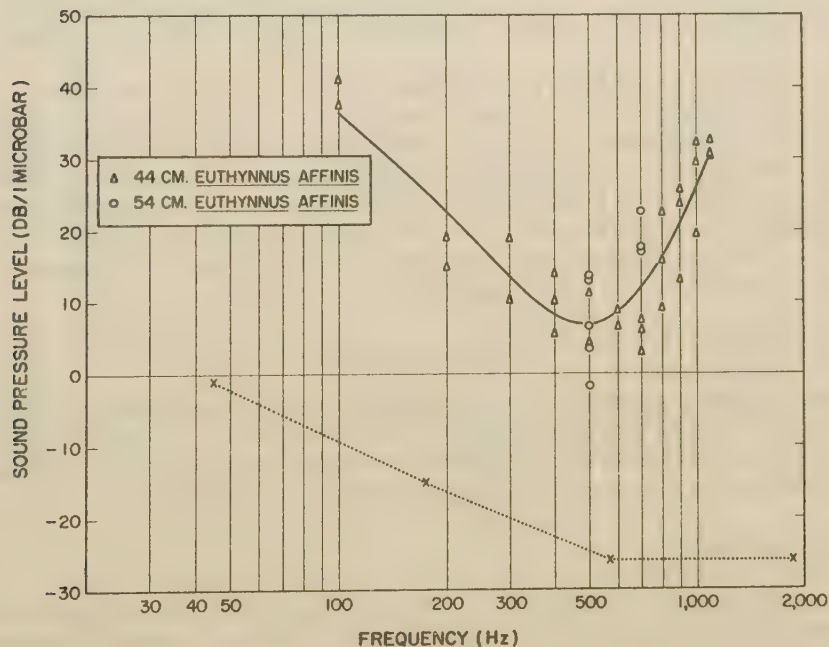


Fig. 1 Acoustic sound pressure thresholds of two Euthynnus affinis. Dotted line indicates background noise and is plotted as total noise in the bandwidth from data given by Iversen (1967)

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4 NATURE OF THE STIMULUS

Thresholds for fish are usually described in relation to pressure, since pressure-sensitive hydrophones have been a standard device for underwater acoustic measurements. Recent work on goldfish, Carassius auratus (Enger, 1966; Jacobs and Tavalga, 1967) however, has re-emphasized the question of whether fish are sensitive to both the displacement of water particles produced by underwater sound sources and to the propagated pressure wave.

Enger (1966) obtained pressure thresholds for the goldfish, converted the thresholds to displacements (expressed as Angstrom units) and found the displacements were about the same for all distances from the goldfish to the underwater sound source, and also with the sound source in air. The pressure thresholds varied with the distance. He concluded that for acoustic thresholds particle displacement is a better characteristic to measure than pressure. Jacobs and Tavalga (1967) also tested C. auratus with the sound source in air, but obtained pressure thresholds at frequencies below 1,000 Hz. that were about 10 to 20 db lower than those obtained by Enger with the sound source by air. Jacobs and Tavalga concluded the goldfish were responding to pressure, since pressure measurements in the water and in the air adjacent to their tank were almost identical, although they did not specify the mechanism by which the pressure stimuli were detected. They also pointed out that the equations given by Harris (1964) for the conversion of pressure to displacement values, and used by Enger (1966), are of questionable validity when used for converting pressure measurements to particle displacements for water masses with nearby boundaries, as in small aquaria.

A pressure wave produces its own displacements and can also stimulate a swim bladder to produce displacements, i.e., near-field effect (Harris and van Bergeijk, 1962). Van Bergeijk (1964) has made a fairly convincing case that all hair cells of the acousticolateralis system are sensitive to displacement. Assuming tuna respond to acoustically produced particle displacements, it is not known precisely how the required values are generated - whether by the pressure wave, by the swim bladder vibrating in response to the pressure wave, or by a combination of pressure wave displacements and other near-field displacements.

5 COMPARISON OF RESPONSE TO SOUND BY Euthynnus affinis AND YELLOWFIN TUNA

Mean thresholds of sound pressure for E. affinis were consistently higher than those obtained by Iversen (1967) for yellowfin tuna (Fig. 2). The differences might be due to the fact that the yellowfin tuna have a swim bladder but E. affinis do not, or to the effect of flow noise, since E. affinis swam the faster.

5.1 Role of swim bladder

The most obvious difference between the two species that might account for the more sensitive responses of the yellowfin tuna is the lack of a swim bladder in E. affinis, since the lowest hearing thresholds have been recorded from species with swim bladders. These records have been obtained from Ostariophysi that have the swim bladder connected to the inner ear by a series of Weberian ossicles, such as in the goldfish (Jacobs and Tavalga, 1967). Teleosts without this type of specialization generally have higher thresholds than Ostariophysi, but the range of thresholds between species is wide. Tavalga and Wodinsky (1963) who tested nine species of non-ostariophysian marine teleosts, all with swim bladders, found a range of 47 db in the lowest threshold values. They also found that thresholds among species with the same general type of swim bladder may differ as much as 15 db.

The influence of the swim bladder of the yellowfin tuna on its hearing would presumably be due to the general ability of a swim bladder to transform variations in pressure into particle displacements that are detectable by the hair cells in the

acousticolateralis system (Harris and van Bergeijk, 1962; van Bergeijk, 1964). Whether or not the yellowfin tuna swim bladder converts pressure variations into particle displacements large enough to be detected by the inner ear or lateral line is uncertain, since the transmission of displacement energy by a swim bladder not connected to the inner ear is probably less efficient than by a swim bladder that transmits displacements directly via the Weberian ossicles (van Bergeijk, 1964). The anterior portions of the yellowfin tunas' swim bladders were about 6 to 7 cm from the inner ear, and the lateral walls of the bladders were about 3.5 cm from the closest flank lateral-line organs (based on measurements of another 53-cm yellowfin tuna); these distances would undoubtedly cause attenuation of the signal. Since the swim bladder of the yellowfin tuna is closely attached to the underside of the fifth to the eighth vertebrae (Iversen, 1967), however, it might aid in signal transmission via the spinal column to the skull and inner ear.

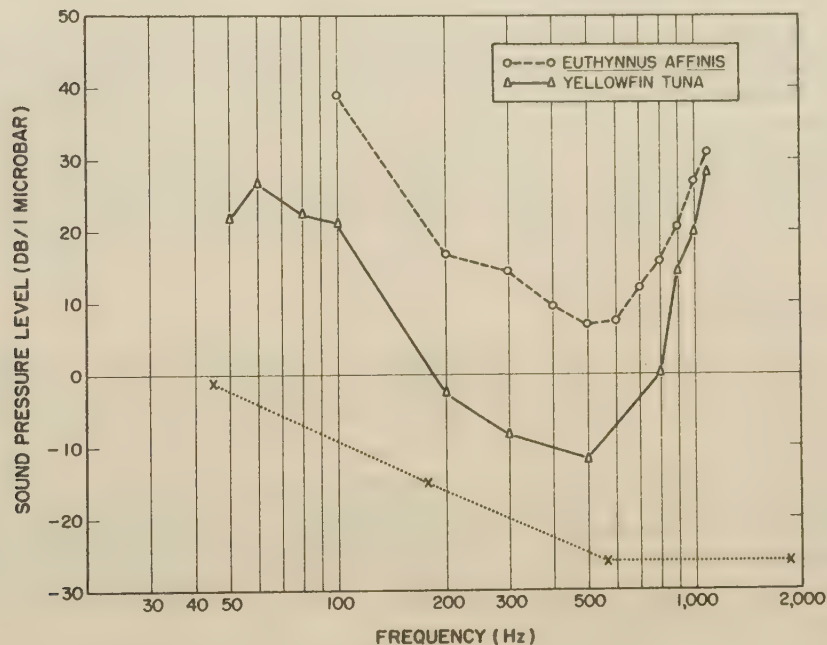


Fig. 2 Mean acoustic sound pressure thresholds for Euthynnus affinis and yellowfin tuna. Dotted line indicates background noise and is plotted as total noise in the bandwidth from data given by Iversen (1967)

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The swim bladder could overcome poor transmission and attenuation by acting as a resonator and amplifying the signal. If we treat the swim bladder as a spherical air bubble, the resonant frequency in Hz. is given by dividing 300 Hz. cm. by the bubble radius in centimeters (Tavolga, 1964). On this basis the resonant frequencies of the swim bladders of two yellowfin tuna 66 and 53 cm long, about the size of the yellowfin tuna used by Iversen (1967), were calculated to be about 120 and 200 Hz., respectively. Volumes of their swim bladders were 67 and 13 cc, as measured by a radiographic technique developed by Chang and Magnuson (1968). The radii of spheres with those volumes would be 2.5 and 1.5 cm.

Tavolga (1964) found the actual resonant frequency of swim bladders and small balloons shaped like swim bladders to be two to three times higher than expected, but the rise in energy due to resonance was only 3 to 4 db. Increasing the calculated resonant frequency of the yellowfin tuna swim bladder by a factor of two to three results in resonance at 240 and 600 Hz. A 3- to 4-db resonant rise at those frequencies could account for a part, but not all, of the differences in thresholds between the yellowfin tuna and E. affinis.

Experiments are needed in which thresholds are measured for a tuna tested first with and then without a functional swim bladder. Such experiments cannot be readily performed with a free-swimming tuna, since the precise swimming paths of tuna required for hearing tests would be disrupted by even a modest amount of handling. Electrophysiological experiments with a restrained tuna in a holding apparatus (Rayner and Keenan, 1967) are probably more appropriate. Such experiments should also measure thresholds with the tuna in both a near-field and far-field situation for all frequencies tested.

5.2 Effect of flow noise

Another possible cause of the difference in thresholds may be related to difference between swimming speeds of the two species. The noise produced by hydrodynamic flow around a body increases as the rate of water flow increases past the body. This noise is termed flow noise and is produced by turbulence at the boundary layer, by surface roughness, by eddies produced by structures protruding from the body, and from other types of vibrations. These effects can cause rather large fluctuations in pressure that together with the unsteadiness of the turbulence at the boundary layer generate a sound that is propagated over the entire disturbed region (Skudrzyk and Haddle, 1963). In short, a background noise is created which could mask noises from other sources that impinge on the body of a moving fish.

The swimming speed of E. affinis during the hearing experiments was estimated to be up to 50 percent greater than that of the yellowfin tuna. Thus the flow noise generated by the E. affinis should have been greater than that by the yellowfin tuna. A similar difference would be expected in the field since typical speeds of yellowfin are less than E. affinis (Magnuson, 1966). With greater flow noise a louder incoming sound would be required for detection.

6 RELEVANCE TO FISHING TACTICS

Generalizing from the experimental situation to a field ecological or fishing situation is hampered by a lack of information on the exact nature of the acoustic stimulus to which the tuna respond. The most likely way to use sound in tuna fishing, however, is to produce intense sounds to repel or control the fish. Three techniques based on the use of sound are employed by fishermen in the eastern Pacific to keep tuna from escaping from purse seines (McNeely, 1961). One method is the dropping of small explosives called "cherry bombs" into the water between the seine skiff and the vessel before encircling is completed, between the end of the net and the stern of the vessel when a towline is required, and between the purse lines alongside the vessel before pursing is completed. Another method is running the seine skiff or a speedboat at

full speed between the stern of the vessel and the end of the net when a towline is used. A third method is beating the side of the vessel or seine skiff with a sledge hammer.

Iversen (1967) noted that on two occasions a sudden intense 500 Hz. sound caused a yellowfin tuna to dash across the holding tank from a position close to the underwater transducer. Suyehiro, Tsukamoto, and Saito (1957) reported that Pacific mackerel (Scomber japonicus) were deflected away from small explosives when the sound pressure was over 57 db. The explosive was within 2 m of the mackerel. Since it is desirable to control the movements of tuna at distances considerably greater than that, much higher sound levels will be required. These levels may be most readily determined through trial and error.

Tuna purse seines probably cause the fish to increase swimming speed as the encircling operation is completed and during pursing of the net. Since tuna may be more insensitive to sound when swimming faster, very loud noisemakers would be required to prevent them from escaping from the net. These sounds should include frequencies in the most sensitive portion of the tuna hearing, between about 300 and 700 Hz. Banging with hammers on the engine-room plates of the R/V CHARLES H. GILBERT⁴ produced sounds with frequencies from 100 to over 4,400 Hz. Intense sounds from explosives and such devices as underwater spark gaps also include frequencies in this range (Padberg, 1960; Kuroki and Kumanda, 1961).

Continuous engine noises from a large fishing vessel or seine skiff probably will not deflect the tuna. Schools of tuna being caught by pole and line are commonly observed to approach within a few meters of the fishing vessel, even when it is under way, to eat the live bait that is being chummed. In fact, a skipjack tuna was observed to swim into the revolving propeller of the R/V CHARLES H. GILBERT during fishing. Continuous sounds do not appear to have any effect on the fast-swimming tuna, possibly because of flow noise, or possibly because their feeding drive dominates any aversion to the engine noise. I have observed skipjack tuna swim alongside the R/V CHARLES H. GILBERT for 10 min within 3 m of the engine room compartment when the ship's speed was 9 kn and no fishing was in progress.

Intermittent ship noises may have an effect, however. For example, on two recent occasions aboard the R/V CHARLES H. GILBERT while skipjack tuna were being fished off the stern, the school swam away momentarily from the vessel when the engine speed was increased. A loud sound accompanied the increase in speed as the gears meshed; it was then that the school turned away. They returned to their previous position within 4 or 5 sec. Visual stimuli may also have had an effect, for the propeller speed increased at the same time the sound was heard.

Sounds might also be used to attract tuna. Moulton (1960) and Iversen (1967) listed several types of tuna prey that produce sounds with frequencies audible to tuna. Whether these sounds will attract tuna remains to be demonstrated.

The use of sonars to locate and track schools of tuna probably has little effect on the fish. The signals from fish-finding sonars would probably not even be detected by tuna since these sonars operate at frequencies much higher than 1,100 Hz., approximately the upper limit of tuna hearing. Also, the high frequencies produced by fish-finding sonars should not cause any physiological damage to tuna. Yoshimuta and Mitsugi (1956) reported damage to the red corpuscles, scales, and viscera of medaka (Oryzias latipes), goldfish (Carassius auratus), and carp (Cyprinus carpio) when they were subjected to high frequency (24,000 Hz.) sound within a distance of 4 m from the transducer for periods from 5 to 30 min. A tuna would not remain that close to a sonar transducer for over 5 min.

⁴Data in the files of the U.S. Bureau of Commercial Fisheries Biological Laboratory, Honolulu, Hawaii.

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Westenberg (1953) has speculated that sonic stimuli from live baitfishes may have been responsible for the immediate attraction of tuna from distances greater than 35 m. This possibility cannot be ruled out, but the appearance of the tuna after baitfish were chummed may well have been due to visual attraction caused by the baitfish diving downwards and intercepting other tuna that were directly below the fishing boat and unseen by the fishermen.

7 REFERENCES

- Andreas, B.G., Experimental psychology. New York, John Wiley and Sons, Inc., 595 p.
1960
- Chang, R.K.C. and J.J. Magnuson, A radiographic method for determining gas bladder
1968 volumes of fish. Copeia, 1968(1):187-9
- Enger, P.S., Acoustic threshold in goldfish and its relation to the sound source
1966 distance. Comp.Biochem.Physiol., 18:859-68
- Harris, G.G., Considerations on the physics of sound production by fishes. In Marine
1964 bio-acoustics, edited by W.N. Tavolga, New York, Pergamon Press, pp. 233-47
- Harris, G.G. and W.A. van Bergeijk, Evidence that the lateral-line organ responds to
1962 near-field displacements of sound sources in water. J.acoust.Soc.Am.,
34:1831-41
- Iversen, R.T.B., Response of yellowfin tuna (Thunnus albacares) to underwater sound.
1967 In Marine bio-acoustics, edited by W.N. Tavolga, New York, Pergamon Press,
vol.2:105-21
- Jacobs, D.W. and W.N. Tavolga, Acoustic intensity limens in the goldfish. Anim.Behav.,
1967 15:324-35
- Kuroki, T. and K. Kumanda, The effects of underwater explosions for the purpose of
1961 killing predacious fishes. Bull.Fac.Fish.Hokkaido Univ., 12(1):16-31
(In Japanese with English summary)
- Magnuson, J.J., A comparative study of the function of continuous swimming by scombrid
1966 fishes. In Symposium on biological studies of tunas and sharks in the
Pacific Ocean. Proc.Pacif.Sci.Congr., 11(7):15 (Abstract)
- McNeely, R.L., The purse seine revolution in tuna fishing. Pacif.Fisherm., 59(7):27-58
1961
- Miyake, I., Reaction of tunas and other fishes to stimuli.4. Observations on sound
1952 production and response in tuna. Spec.sci.Rep.U.S.Fish Wildl.Serv.,
(91):59-68
- Moulton, J.M., Swimming sounds and the schooling of fishes. Biol.Bull.mar.biol.Lab.,
1960 Woods Hole, 119(2):210-23
- Nakamura, E.L., Observations on the behavior of skipjack tuna, Euthynnus pelamis, in
1962 captivity. Copeia, 1962:499-505
- Padberg, L.R., Jr., Novel sound sources. Res.Dev.Rep.U.S.Navy Electronics Lab.,
1960 (990):63 p.
- Rayner, M.D. and M.J. Keenan, Role of red and white muscles in the swimming of skipjack
1967 tuna. Nature, Lond., 214(5086):392-3

- Skudrzyk, E.J. and G.P. Haddle, Flow noise, theory and experiment. In Underwater
1963 acoustics, edited by V.M. Albers, New York, Plenum Press, pp. 255-78
- Suyehiro, Y., et al., Movements of the fish in response to sound stimuli with refer-
1957 ence to sound intensity. Jap.J.Ichthyol., 6(4-6):136-40
- Tavolga, W.N., Sonic characteristics and mechanisms in marine fishes. In Marine
1964 bio-acoustics, edited by W.N. Tavolga, New York, Pergamon Press, pp. 195-211
- Tavolga, W.N. and J. Wodinsky, Auditory capacities in fishes: pure tone thresholds in
1963 nine species of marine teleosts. Bull.Amer.Mus.nat.Hist., 126:179-239
- _____, Auditory capacity in fishes: threshold variation in the blue-striped
1965 grunt, Haemulon sciurus. Anim.Behav. 13(2/3):301-11
- Timofeev, G.F., Study of sounds produced by sardine and tuna. Ryb.Khoz., 41(7):25-7
1965 (In Russian) (English translation in files of Bureau of Commercial Fish-
eries Biological Laboratory, Honolulu, 1966, 5 p.)
- van Bergeijk, W.A., Directional and nondirectional hearing in fish. In Marine bio-
1964 acoustics, edited by W.N. Tavolga, New York, Pergamon Press, pp. 281-99
- Westenberg, J., Acoustical aspects of some Indonesian fisheries. J.Cons.perm.int.
1953 Explor.Mer, 28(3):311-25
- Yoshimuta, C. and S. Mitsugi, Effect of supersonic wave on behavior of fish.
1956 Bull.Tokai reg.Fish.Res.Lab., 13:51-60 (In Japanese with English summary)

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Acknowledgments

I thank Per S. Enger, David W. Jacobs, John J. Magnuson, Eugene L. Nakamura, Phyllis H. Cahn, and Howard E. Winn for their review of this report. The assistance of Hunt E. Johnsen and John J. Naughton in conducting the experiments is acknowledged. Tamotsu Nakata prepared the figures.

OBSERVATIONS ON THE REACTIONS OF THE SARDINE
(Sardina pilchardus WALB.)
TO INTERMITTENT WHITE LIGHT

by

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Abstract

Observations on the reactions of the sardine to intermittent white light in captivity are reported and discussed.

It was found that the responses of fish tested depended on the duration of interruption of light at the frequencies used, i.e. 10 and 40 per minute and probably also on the fish's previous schooling affinity.

Changes from the polarized school to the scattered pattern, and vice versa, occurred quickly following changes in the light conditions.

The opinion is expressed that light interruptions, at appropriate frequencies and duration, as a separate factor or in alternation with the continuous light, might be applied in sardine fishing.

OBSERVATIONS SUR LES REACTIONS DE LA SARDINE
(Sardina pilchardus WALB.)
A LA LUMIERE BLANCHE INTERMITTENTE

Résumé

Les observations sur les réactions à la lumière blanche intermittente, de la sardine en captivité, sont rapportées et discutées.

On a trouvé que la réaction du poisson dépend de la durée de l'interruption de la lumière aux fréquences utilisées (10 et 40 par minute) et probablement aussi de la tendance antérieure du poisson à se réunir en bancs.

Des modifications, de bancs polarisés à la dispersion et réciproquement, se sont produites rapidement après changements des conditions d'éclairage.

L'auteur exprime l'opinion que des interruptions de la lumière, à des fréquences et pendant des durées convenables, isolément ou en alternance avec un éclairage continu, pourraient être utilisées dans la pêche de la sardine.

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OBSERVACIONES SOBRE LAS REACCIONES DE LA
SARDINA (Sardina pilchardus WALB.) A LA
LUZ BLANCA INTERMITENTE

Extracto

Se presentan y discutan las observaciones sobre las reacciones de la sardina en cuatividad a la luz blanca intermitente.

Se encontró que las reacciones de los peces examinados dependían de la duración de la interrupción de luz a las frecuencias usadas esto es 10 y 40 por minuto y, probablemente, también dependen de la afinidad previa de los peces a formar cardúmenes.

Los cambios del cardúmen polarizado a un estadio disperso y viceversa, ocurrió en poco tiempo como consecuencia de los cambios en la condición de la luz.

Se opina que las interrupciones de luz, a frecuencia y duración apropiadas y como factor adicional o en alternación con la luz continua, pueden ser aplicadas en la pesca de sardina.

1 INTRODUCTION

It was thought that intermittent light of an appropriate frequency and duration could transform a school or feeding aggregation of sardines into a disoriented group and that such a response might find some application in sardine fishing. Therefore, this study was undertaken to investigate the reactions of sardines subjected to intermittent white light, as a separate factor and in alternation with periods of continuous light, especially the response of a school of sardines to become a broken group incapable of directional movement and coordinated response to stimuli.

The experiments were carried out at the Institute of Oceanography and Fisheries, Split.

2 MATERIAL AND METHODS

The experiments were carried out on 50-58 sardines with an initial mean total length of 14.8 cm. The sardine lived previously in captivity and were in good condition. They did not show signs of sexual activity.

Sardines were kept in a rectangular tank 295 x 119 x 120 cm. At night and during very cloudy weather the room with tanks was illuminated by an artificial light of low intensity. The experiments were carried out at temperatures ranging from 19.3 to 22.1°C.

A tungsten filament bulb with a transformer was used in the experiments. The interruption of light was controlled by an automatic electric interrupter. The intensity of light, measured in the middle of the tank a little above the surface of the water, ranged from 94-110 lum/sq.ft. The same light intensity was maintained during each experiment.

Before each experiment the fish were exposed for one hour to continuous light of the same intensity as that used during the experiment. For each experiment documented here the previous group behaviour is indicated.

Sixteen experiments were carried out to analyze the behaviour of sardines during intermittent light following continuous light. The frequencies and duration of light interruption used were:

- 10 interruptions per minute, with durations of 5.5, 3.0 and 0.5 sec
- 40 interruptions per minute, with durations of 1.0 and 0.5 sec

Our attention was focused on the longer interruptions considered of greater possible application in fishing.

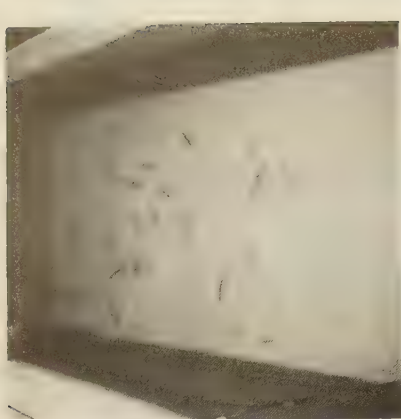
In four experiments, intermittent light of ten long interruptions (each of 5.5 sec) per minute was alternated with a period of continuous light. The intermittent light period lasted one minute; the continuous light period lasted three minutes, one minute, 30 seconds and 20 seconds.

The behaviour of sardines was analyzed mostly from photographs. These were taken by an electronic flashlight of 100 w/sec with a flash duration of 1/300 sec.

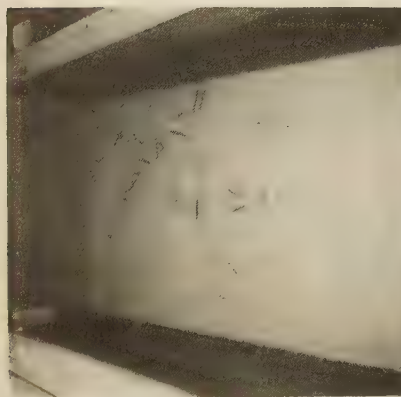
3 RESULTS OF EXPERIMENTS

During these experiments, under conditions of continuous lighting the sardines were nearly always polarized, in a typical school; in only one experiment did the fish form merely a loose aggregate. When polarized, the fish always moved counter-clockwise. Individual fish in poor condition generally were isolated from the school or aggregation.

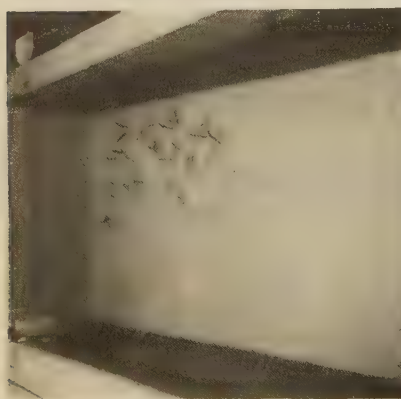
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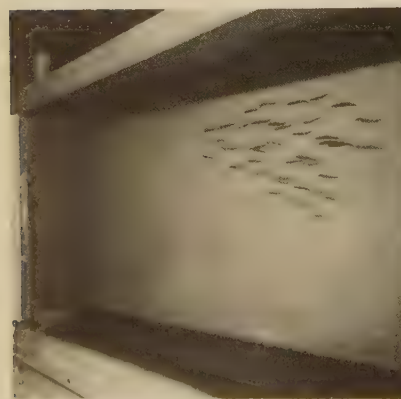
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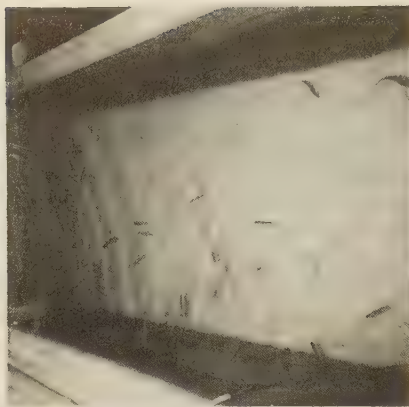
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b



a



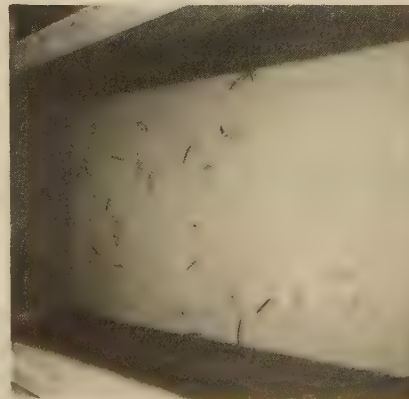
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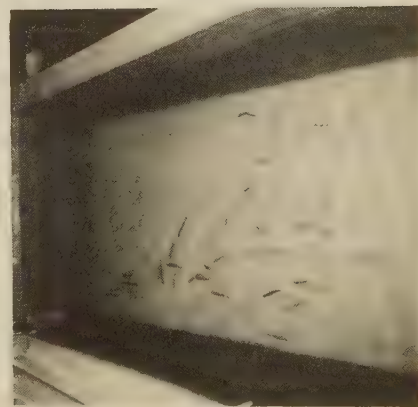
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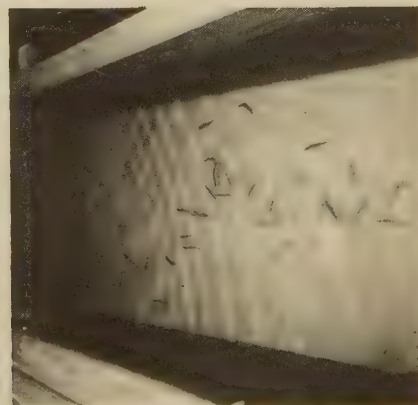
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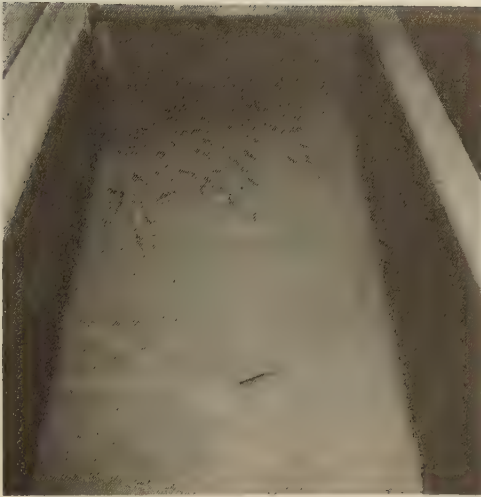


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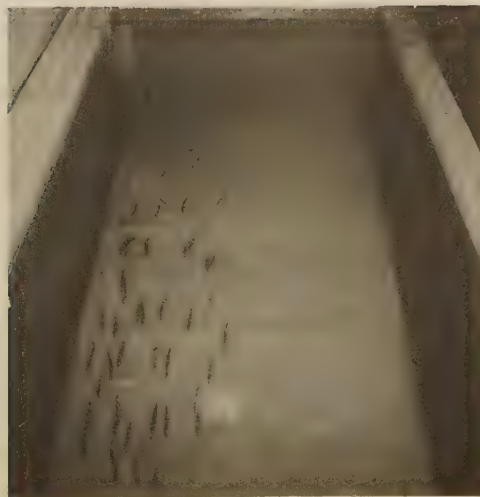
Fig. 1 Changes in the behaviour of sardines after switching from continuous light (a); to the intermittent light with ten interruptions of 5.5 secs per minutes (b-g); and again to the continuous light (h-j).



a



b



c

Fig. 2 Behaviour of sardines after switching from continuous light (a); to the intermittent light with ten interruptions of 0.5 sec, per minute (b and c).

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3.1 Intermittent light with low frequency of interruption: 10 per minute

Twelve experiments were conducted with 10 light interruptions per minute; in most of the experiments each interruption lasted 5.5 sec.

3.1.1 Interruptions of 5.5 sec each Immediately after switching from continuous light to intermittent light of 10 long interruptions (5.5 sec) per minute, the polarization of sardines disappeared. Figures 1a and b show two successive photographs, the second taken 1 sec after starting the intermittent light period. The fish swam slowly in all directions, some of them showing loss of equilibrium, and the group gradually dispersed as shown by subsequent photographs (Fig. 1c to f) taken at a little more than 3 sec intervals. The changes occurred quickly, i.e. within 14 sec. Similar behaviour of sardines in darkness has been recorded earlier (Muzinić, 1964).

Exposure of sardines to intermittent light of 10 long (5.5 sec) interruptions per minute, prolonged for a 1 h period, did not essentially change their behaviour (Fig. 1g). Loukashkin and Grant (1959) found that a prolonged exposure of *Sardinops caerulea* to darkness did not lead to schooling formation in spite of a gradual restoration of equilibrium in the fish.

Immediately after switching from intermittent light to the continuous light in the same experiment, the sardines avoided the walls of the tank, and concentrated themselves as shown by three successive photographs (Fig. 1h to j), the first taken after 1 sec and the next two at a little more than 3 sec intervals. However, within a total of 14 sec they did not form a polarized group.

In *Sardinops caerulea*, Loukashkin and Grant (Ibid.) found that the school broke up in darkness, but 5 to 10 min after exposure to a white light, the school reformed.

3.1.2 Interruptions of 0.5 sec each Switching from a period of continuous light to a period of intermittent light of 10 short interruptions (0.5 sec) per minute caused a shock effect of short duration as shown by three successive photographs of the sardines. These photographs were taken at 3 sec intervals after changing to the intermittent light (Fig. 2a, b and c). The shock effect occurred within the first 9 sec. After the shock effect wore off the fish moved in a loose polarized group in the same counterclockwise direction as before (Fig. 2c).

3.1.3 Interruptions of 3.0 sec each At intermittent light of 10 interruptions of intermediate duration (3.0 sec) per minute, two group patterns were recorded. At the end of the light phases the sardines were polarized (Fig. 3a). Conversely, at the end of the dark phases they showed loss of the polarization (Fig. 3b). However, at the end of the dark phases the fish remained grouped and thus were able to polarize themselves within the relatively short, light phases of only 3 sec. Previous to these tests when the sardines were exposed to continuous light they formed a dense school.

Exposure of the sardines to this intermittent light for a prolonged period of 1 h did not change their behaviour.

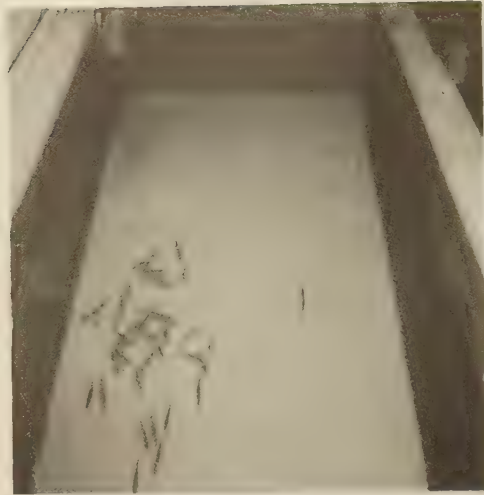
3.2 Intermittent light with a higher frequency of interruption: 40 per minute

Four experiments with 40 light interruptions, each interruption either 1.0 or 0.5 sec, per minute were carried out.

3.2.1 Interruptions of 1.0 sec each When intermittent light of 40 interruptions (each 1.0 sec) per minute, was put on after a period of continuous light, the sardines did not show a complete polarization after 13 sec (Fig. 4a). However, they moved in a group along the walls of the tank as shown by four successive photographs



a



b

Fig. 3a and b Two group patterns recorded in sardines exposed to the intermittent light with ten interruptions of 3.0 secs per minute.

taken at a little more than 3 sec intervals (Fig. 4a to d). The movements of the fish in this incompletely polarized group seemed to be rather slow. After 1 h of this intermittent light the fish showed a scattered pattern (Fig. 4e). Under continuous lighting the sardines again formed a dense school.

3.2.2 Interruptions of 0.5 sec each At intermittent light of 40 shorter interruptions (0.5 sec) per minute put on after the continuous light the sardines, previously in a dense school, lost some of their polarization as shown by a photograph taken more than 4 sec after putting on the intermittent light (Fig. 5a). However, they remained in a group. After 8 sec the fish were completely polarized (Fig. 5b).

3.3 Intermittent light alternating with continuous light

The sardines exposed alternately to intermittent light of 10 long interruptions (5.5 sec) per minute and to continuous light, each condition lasting 1 min, showed a rather high degree of concentration and tended to move in one direction 3 sec after putting on the continuous light (Fig. 6a). At the end of the continuous light period the sardines were in a dense school moving counter-clockwise (Fig. 6b). Later during the same experiment a rather high degree of polarization sometimes appeared 3 sec after the beginning of the continuous light phase (Fig. 6c). In two further experiments with the continuous light phase lasting only 30 or 20 sec the fish formed a dense school at the end of that phase. In all three cases the sardines were in a dense school before the experiments.

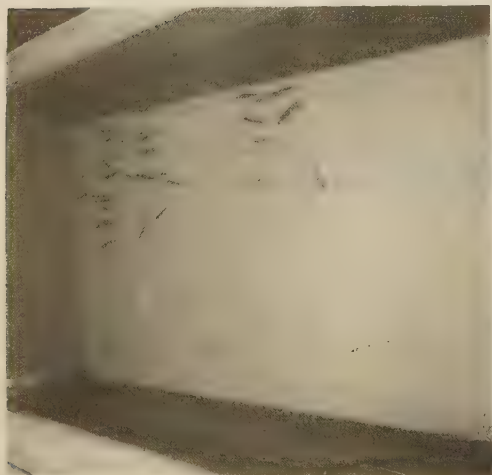
The group behaviour of sardines subjected to intermittent light, after their exposure to the continuous light, depended not only on the frequency, but also on the duration of the light interruptions. It was clearly shown that intermittent light with 10 interruptions per minute caused: scattering of the fish with long interruptions of 5.5 sec; little disturbance to the fish with short interruptions of 0.5 sec; and at intermediate interruptions of 3.0 sec, there was some loss of polarization which, however, was regained between interruptions.

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c

Fig. 4 Behaviour of sardines at
the intermittent light
with 40 interruptions of
1.0 sec per minute



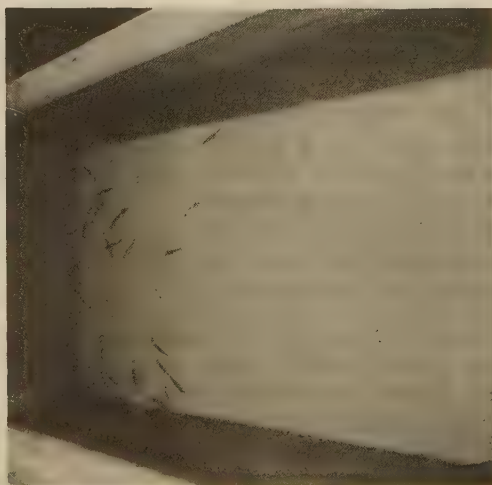
b



e



a



d

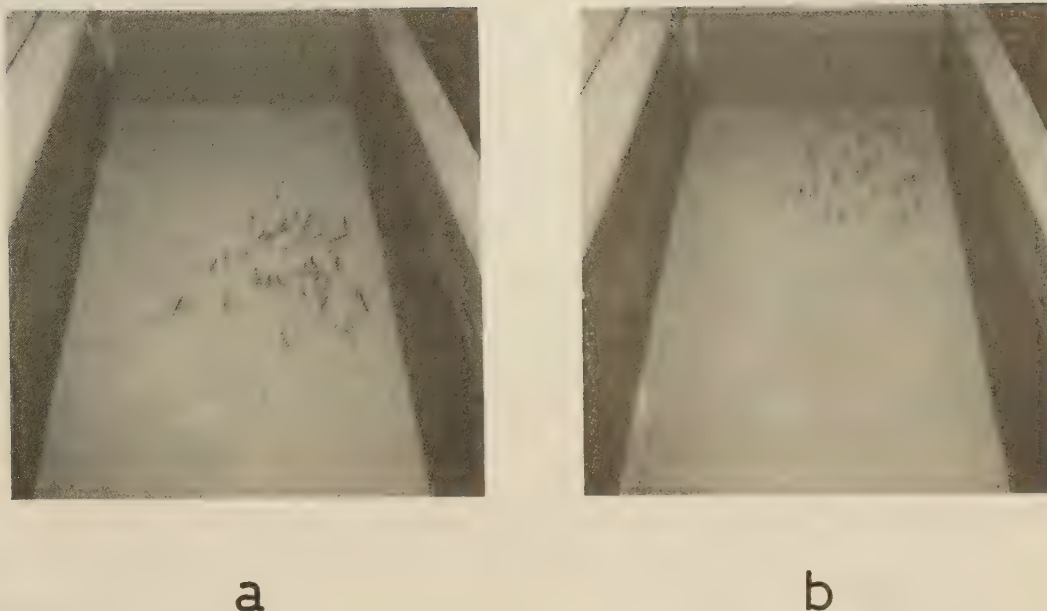


Fig. 5a and b Behaviour of sardines at the intermittent light with 40 interruptions of 0.5 sec per minute.

Difference in sardine behaviour was also found at 40 interruptions of light per minute lasting either 1.0 or 0.5 sec.

However, at the same frequency and duration of interruptions some differences in the behaviour of sardines occurred. They were recorded at higher frequency of interruption. These differences seemed to have been determined by different schooling affinity.

The loss of polarization of sardines at the period of intermittent light took place immediately. The dispersion of the fish followed gradually.

The speed of the polarization of sardines at the continuous light varied. In a fully scattered group of sardines, like that appearing at intermittent light of 10 long interruptions (each of 5.5 sec) per minute, a complete polarization took place within 30 sec after putting on the continuous light. However, the process of polarization began early. Immediately after putting on the continuous light the fish started to concentrate.

If the sardines were grouped when the intermittent light period was started, they polarized themselves quickly. In the experiments with 10 interruptions per minute (each lasting 3.0 sec) the fish were polarized by the end of each 3 sec light phases.

Therefore, both the loss in polarization of sardines at the intermittent light and their later polarization at the continuous light were quick processes.

Full polarization does not appear to be necessary for the directional movement of sardines.

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a



b



c

Fig.6a-c Behaviour of sardines when alternating intermittent light with ten interruptions of 5.5 sec per minute with continuous light.

It may be possible to apply these results in sardine fishing. When encircling a school of sardines it might be effective to use alternating periods of continuous light and intermittent light (e.g. low frequency and long duration of interruptions) to control the schooling and disorientation of sardines.

The intermittent light has already been applied in fishing. Loukashkin and Grant (1959) found that Sardinops caerulea avoided a flashing beam (up to 60 interruptions per minute) in total darkness and aggregated in the darker part of the tank. A continuous beam caused the fish to school and resume circular movement.

A flashing light is used in California purse-seine fishing to keep sardines within the seine until the net has been closed (Loukashkin and Grant, Ibid.). The Spanish fishermen use also the flashing light to keep the enclosed fish away from the wings of the purse-seine when they move quickly or swim in a deep layer. Flashes of a few seconds duration are produced every few minutes by a submerged 60 W electric bulb (Andreu, 1957).

In the Black Sea the intermittent light is used in the demersal fisheries (Sara, 1962). A 50 to 1,000 W bulb, fastened to the upper part of the trawl, produces flashes lasting 2 to 3 sec every 12 to 15 sec.

4 REFERENCES

- Andreu, B., Aplicaciones de la luz intermitente sumergida en la pesca de la sardina.
1957 Reun.Product.Pesq., 3:32-7
- Loukashkin, A.S. and N. Grant, Behavior and reactions of the Pacific sardine,
1959 Sardinops caerulea (Girard) under the influence of white and colored
lights and darkness. Proc.Calif.Acad.Sci., 29(15):509-49
- Muzinić, R., Further observations on schooling and aggregating behavior of sardines
1964 (Sardina pilchardus Walb.). Proc.tech.Pap.gen.Fish.Coun.Mediterr.,
7:319-23
- Sara, R., La pêche au feu. Stud.Rev.gen.Fish.Coun.Mediterr., (19):33 p.
1962

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UNDERWATER PHOTOGRAPHY OF FISH BEHAVIOUR IN RESPONSE TO TRAWLS

by

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Abstract

Photographs were taken of fish in front of the foot rope of trawls by means of an underwater camera and flash attached to the square, just behind the head rope. Particular attention was paid to the orientation of large and small fish (mainly gadoids and herring) in relation to the direction of tow. There was marked tendency to swim in the direction of tow, an analysis of vectors showing that this tendency was similar in large and small fish and in visual and non-visual conditions (the threshold for visual responses having been determined by experimental work in tanks).

UTILISATION DE LA PHOTOGRAPHIE SOUS-MARINE POUR REVELER LE COMPORTEMENT DES POISSONS DEVANT LE CHALUT

Résumé

On a photographié, à l'aide d'un appareil sous-marin muni d'un flash électronique et fixé sur le dos du chalut, juste derrière la ralingue supérieure, les poissons se trouvant devant le bourrelet, en s'attachant particulièrement à l'orientation qu'ils prenaient par rapport à la direction du trait qu'il s'agisse de poissons de grande ou de petite taille (principalement Gadidés et harengs). Les animaux ont manifesté une tendance marquée à nager dans la direction du trait, l'analyse des vecteurs révélant le même comportement qu'ils soient grands ou petits, et qu'ils voient ou non le filet (le seuil des réponses visuelles a été déterminé par des expériences en vivier).

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EL USO DE LA FOTOGRAFÍA SUBMARINA DEL COMPORTAMIENTO
DE LOS PECES COMO REACCIÓN A LOS ARTES DE PESCA

Extracto

Se tomaron fotografías de peces situados frente a la relinga baja de los artes de pesca en cuyas viseras y exactamente detrás de la relinga alta se habían montado cámaras fotográficas con flash. Se prestó especial atención a la orientación de los peces grandes y pequeños (principalmente gádidos y arenque) en relación con la dirección en que se movía el arte. Los peces tenían marcada tendencia a nadar en esa dirección, indicando un análisis de los vectores que esta tendencia era similar en los peces grandes y en los pequeños, tanto cuando había visibilidad como cuando no la había (el umbral de las reacciones visuales se determinó mediante trabajos experimentales en estanques).

1 INTRODUCTION

On the basis of aquarium observations made of the behaviour of gadoid fish and herring in response to moving nets, models of nets and other devices, Blaxter and Parrish (1966) concluded that vision was the dominant sense involved. With falling illumination at dusk it was possible to measure a decrease in responsiveness of the fish and a decrease of the "herding ability" of the apparatus under test. This enabled threshold light intensities to be measured, above which visually-controlled responses occurred, and below which they were absent.

The implication of these observations was that fish at night, or in deep water, might be less responsive to approaching trawls and that the herding ability of the ancillary parts of the trawl such as warps, doors, and sweeps would also be substantially lower.

It was necessary to confirm these aquarium results by observations of fish responding to trawls under natural conditions. Though continuous and direct underwater observations by divers equipped with camera might have been the most satisfactory method of investigation, they could not be made in darkness or in deep water. Underwater cine cameras and television also have limited value, because of the artificial light required for their operation in poor conditions of natural illumination.

2 METHODS

It was decided to use camera units consisting of a camera and electronic flash tube contained in a pressure housing (see Craig and Priestley, 1963) attached to various parts of the trawl. The method of rigging is also described by these authors. Usually the camera was attached below the square just behind the centre of the head rope and pointing downwards to photograph fish in front of the foot rope. In a few trials cameras were used at the back and side of the square and also pointing upwards to photograph fish passing over the head rope.

Before each haul the camera was set to take a photograph once per minute and it continued to do this during the haul, which lasted usually 30 to 60 min. The hauls were made between 1961 and 1964 in the northern North Sea at depths from 50-200 m by the research vessels EXPLORER, SCOTIA and CLUPEA. The light intensity was also measured at the time of the haul using an underwater photometer (Craig and Lawrie, 1962) at the sea bed, the timing of the hauls being such that the light intensity was either well above the "visual" or "herding threshold" (>1.0 mc) or well below it (<0.1 mc). In this way it was hoped that the orientation of the fish in relation to the trawl could be studied in visual and non-visual conditions.

3 RESULTS

After printing, the films showed that this technique was successful both for observing fish, especially where crowded in front of the foot rope, and for determining their orientation. There was no great problem in identifying the species of the larger fish, over about 15 cm length, in the photographs. The main species observed were herring (Clupea harengus), cod (Gadus morhua), haddock (Melanogrammus aeglefinus) and whiting (Merlangius merlangus). Examples of some of the best frames are shown in Fig. 1A to F. Identification of smaller fish was much more difficult, especially of the gadoids such as Trisopterus esmarkii and the younger individuals of whiting, haddock and cod.

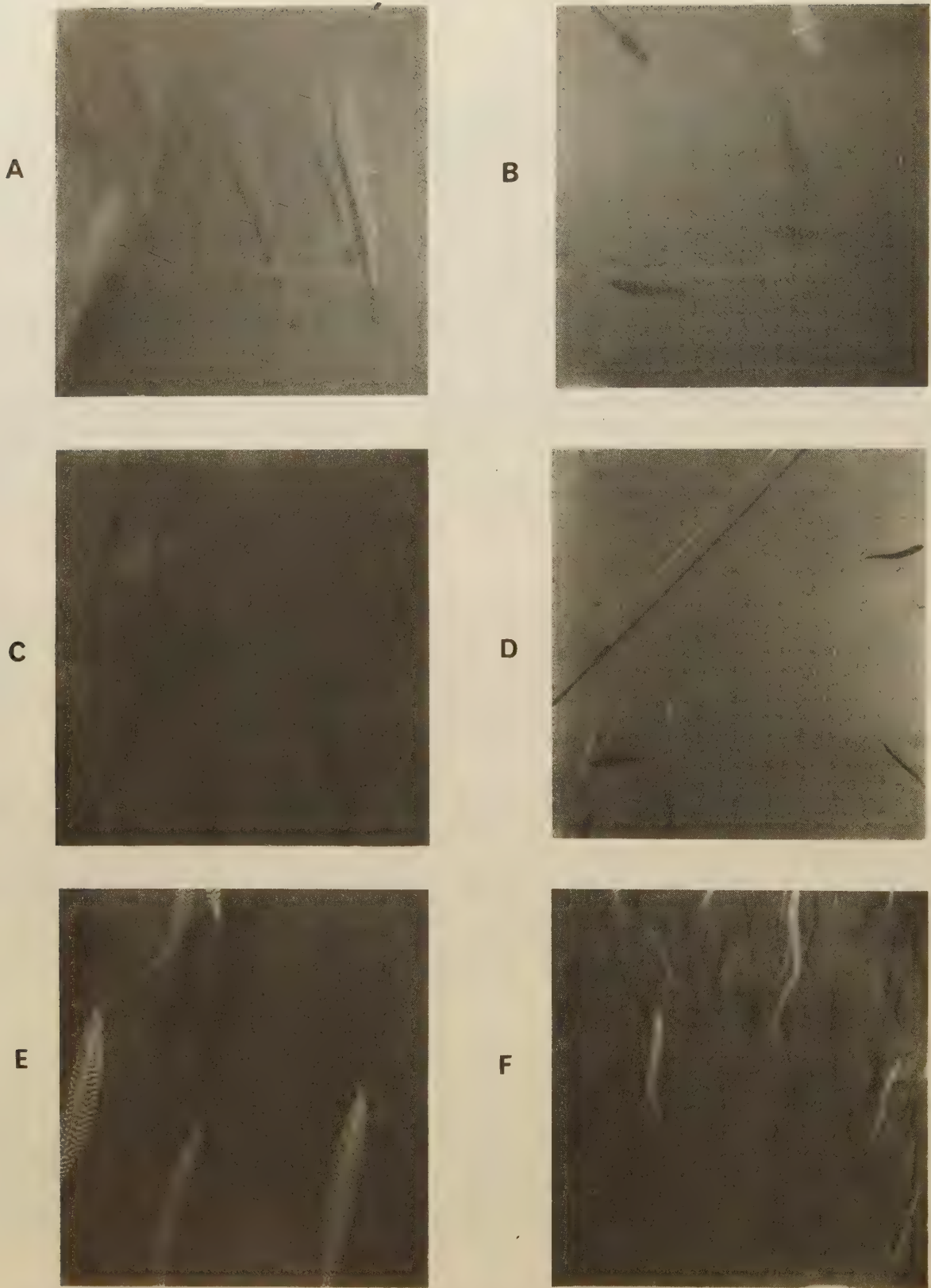


Fig. 1 Underwater photographs. A. cod, visual conditions; B. gadoids, non-visual conditions; C. herring, visual conditions; D. herring, non-visual conditions (the diagonal warp is part of a device to measure spread); E. mackerel, visual conditions (none were caught); F. sandeels, non-visual conditions (none were caught). Note the reduced orientation of the gadoids and herring in non-visual conditions, but not of the sand eels. Direction of tow is to top of page.

In the main analysis, therefore, no attempt was made to differentiate species; all fish were divided into a "large" and a "small" category (i.e. above and below about 15 cm). The orientation of the fish was measured relative to the direction of tow. This direction was clearly seen where parts of the net were visible in the frame; in other cases it was known from the position of the film in the camera, which was itself firmly attached to the net, or from the shadows of the fish, the flash unit always being in front of the camera. In the analysis the fish were grouped into ten sectors each of 36° , as shown in Fig. 2.

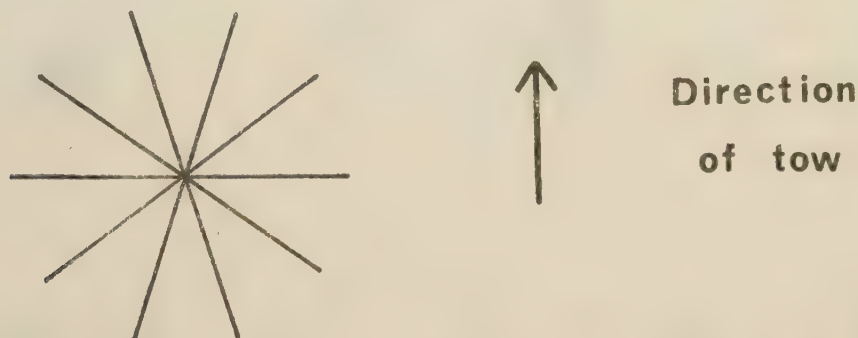


Fig. 2 Diagram showing how the orientation of fish was divided into ten sectors each of 36° during the analysis of photographs.

The orientation in the different sectors is shown in Fig. 3. Each cruise is shown by the name of the research vessel and the year, and for most cruises there are four vector diagrams representing the aggregate number of fish in each sector for all frames taken on that cruise, divided on the basis of

- (a) large fish in visual conditions
- (b) small fish in visual conditions
- (c) large fish in non-visual conditions
- (d) small fish in non-visual conditions

At first sight these results point to small differences in orientation from cruise to cruise, comparing both large and small fish, and visual and non-visual conditions.

For the purpose of statistically analysing the data a unit vector was associated with each fish, the direction of the vector relative to the direction of tow being the mid-angle of the sector in which it lay. A comparison of the various vector sets was made on the basis of the estimated mean vectors of each set and on the degree of concentration (inversely related to the variance) of the individual vectors in each set about their estimated mean. The hypotheses tested by this analysis were as follows:

- (1) was the orientation of vectors random with respect to the direction of tow? If not -
- (2) did the directions of the mean vectors differ from set to set and was there any significant difference in the mean direction between large and small fish and between visual and non-visual conditions?
- (3) was the concentration about the mean vector different between large and small fish and between visual and non-visual conditions?

The results of this analysis can be summarized briefly as follows:

- (a) the direction of orientation was non-random with respect to the direction of tow in all but two of the 29 sets. The two exceptions were:

SCOTIA 1964; small fish; non-visual
 CLUPEA 1962; all fish; non-visual

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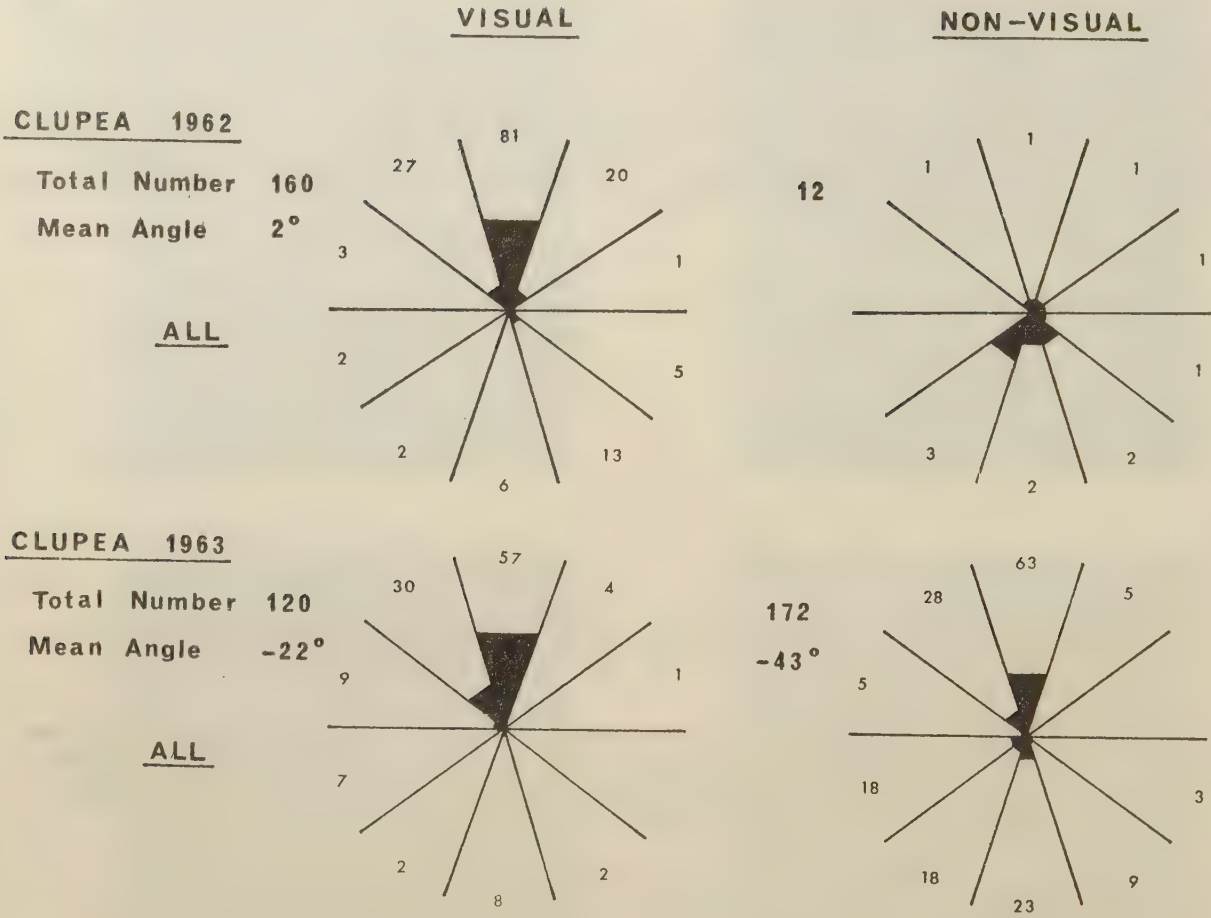
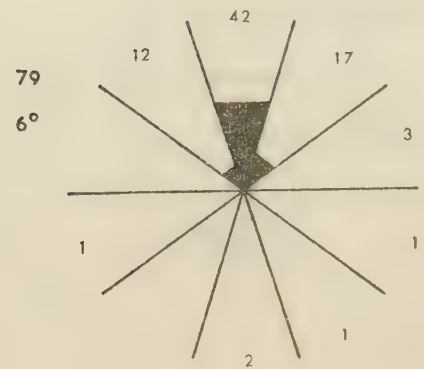
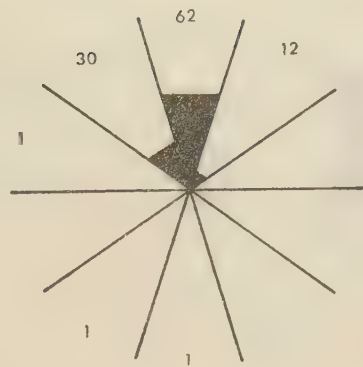


Fig. 3 Vector diagrams showing how large and small fish (above and below about 15 cm length) were orientated in visual (above 1.0 m) and non-visual (below 0.1 m) conditions for different research vessels and different years. The diagrams show percentage of the total in each sector with 100 per cent represented by the full radius. The actual number is given in each sector. The total number of fish and the mean angle of orientation are given beside each diagram. Direction of tow is to top of page.

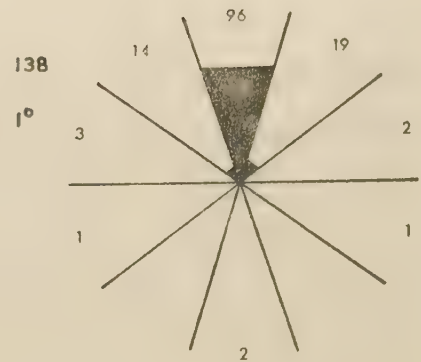
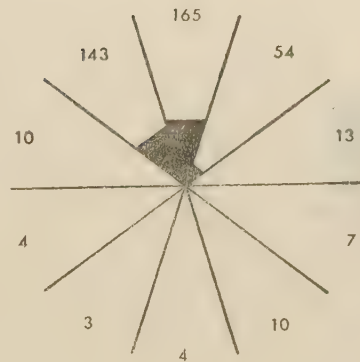
Fig. 3 (Contd)

VISUALNON-VISUALEXPLORER 1962

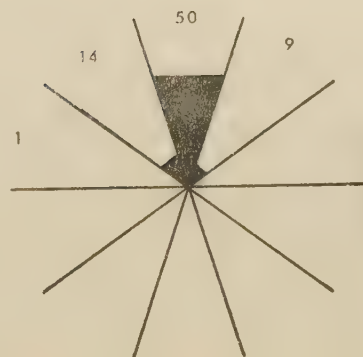
Total Number 107

Mean Angle -7° LARGE

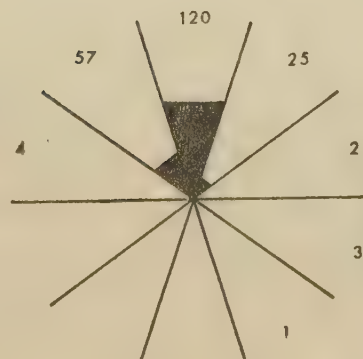
Total Number 413

Mean Angle -8° SMALLEXPLORER 1963

Total Number 74

Mean Angle -3° LARGE

Total Number 212

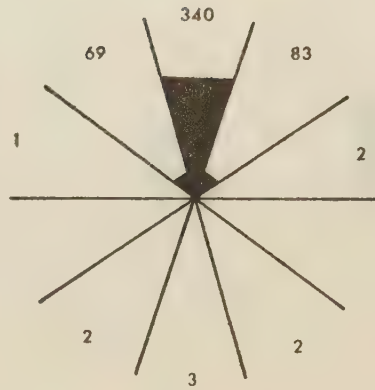
Mean Angle -5° SMALL

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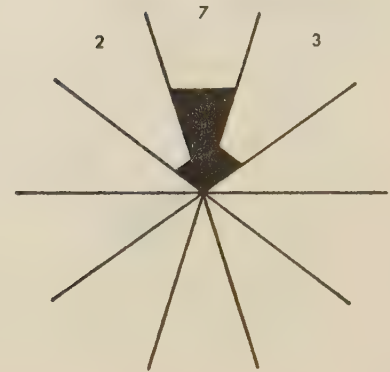
Fig. 3 (Contd)

VISUALNON-VISUALEXPLORER 1964 (1)

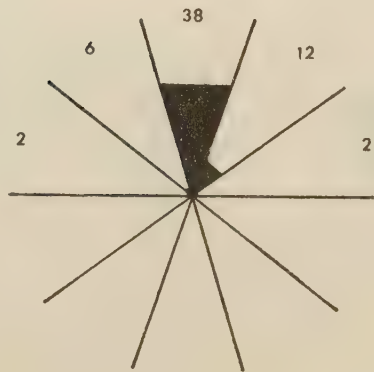
Total Number 502

Mean Angle 1° LARGE

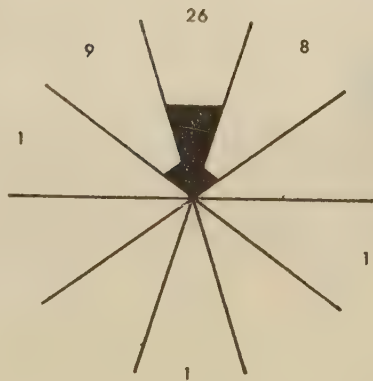
12

 3° 

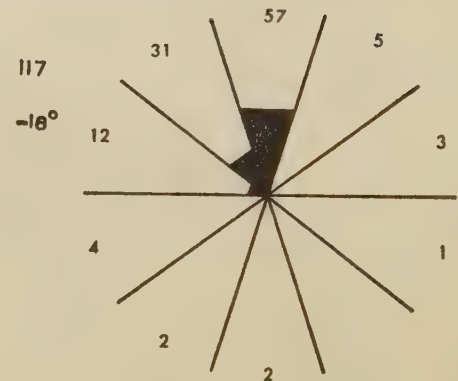
Total Number 60

Mean Angle 4° SMALLEXPLORER 1964 (2)

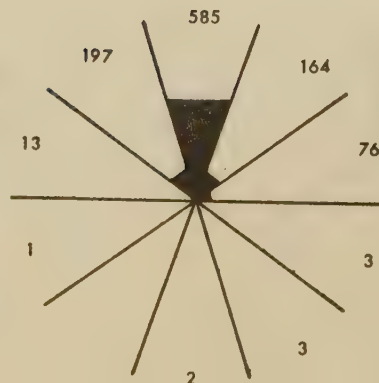
Total Number 46

Mean Angle -1° LARGE

117

 -16° 

Total Number 1044

Mean Angle 3° SMALL

74

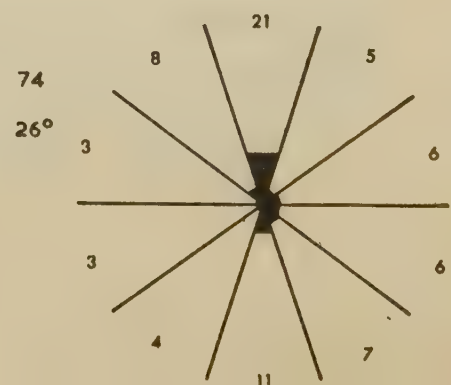
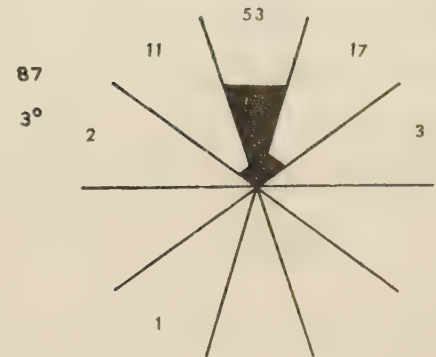
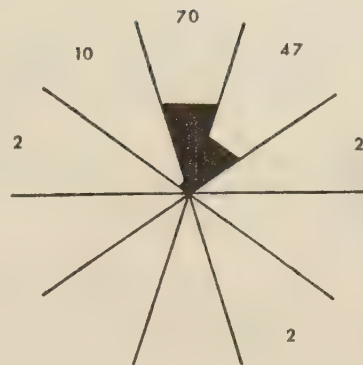
 26° 

Fig. 3 (Contd)

VISUALNON-VISUALSCOTIA 1962

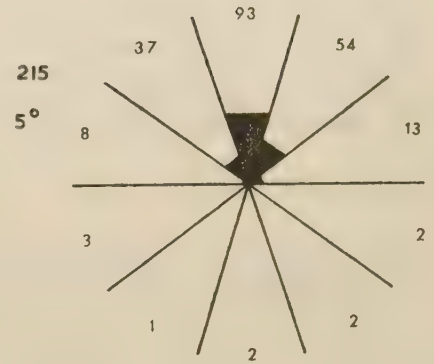
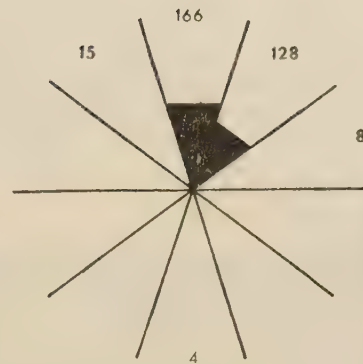
Total Number 133

Mean Angle 11°

LARGE

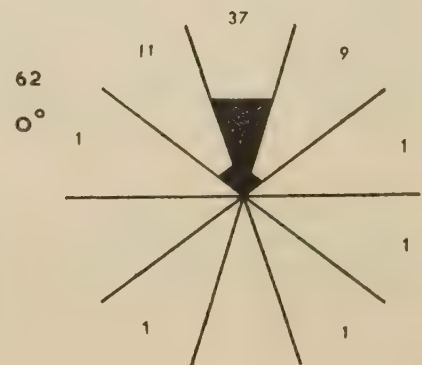
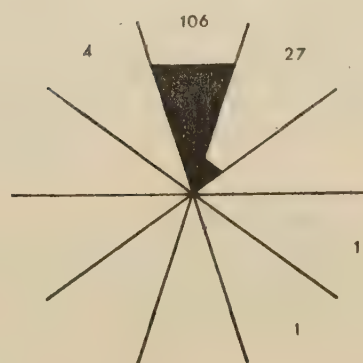
Total Number 321

Mean Angle 15°

SMALLSCOTIA 1963

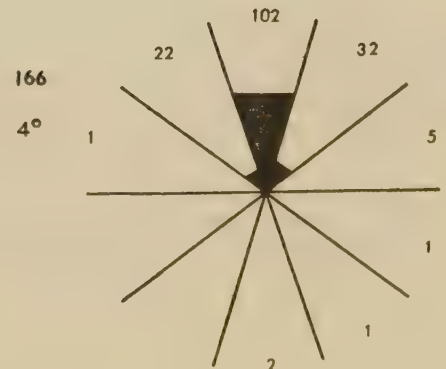
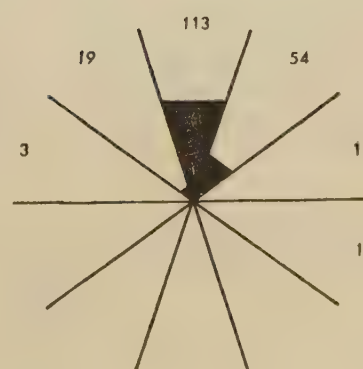
Total Number 139

Mean Angle 7°

LARGE

Total Number 191

Mean Angle 6°

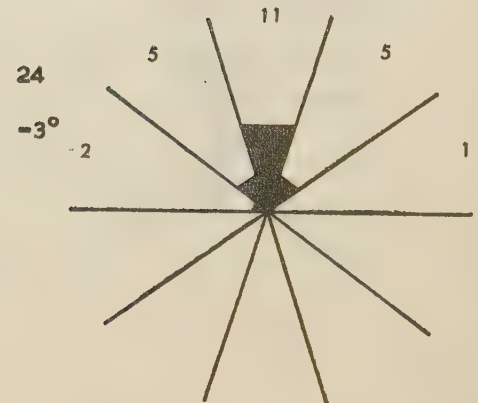
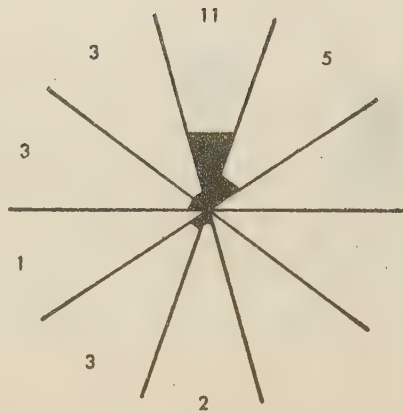
SMALL

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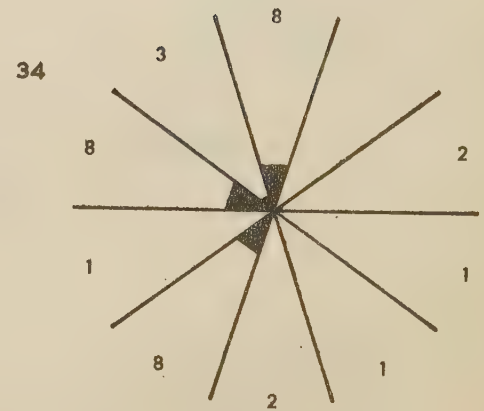
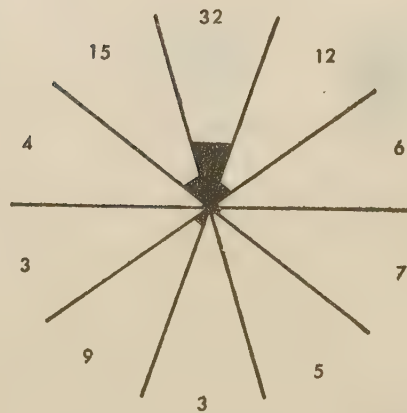
Fig. 3 (Contd)

VISUALNON-VISUALSCOTIA 1964

Total Number 28

Mean Angle -18° LARGE

Total Number 96

Mean Angle 2° SMALL

These data were not considered further.

- (b) the mean directions of orientation, shown against each vector diagram in Fig. 3, were rarely more than 20° either side of the direction of tow and were often very much less. Only in one cruise, CLUPEA 1963, was the deviation greater than $\pm 30^\circ$.

The mean direction of orientation was not homogenous from haul to haul. However, the group averages did not differ noticeably; all were within $3^\circ 30'$ of the direction of tow, i.e.:

large fish; visual	$1^\circ 38'$
small fish; visual	$2^\circ 27'$
large fish; non-visual	$-3^\circ 23'$
small fish; non-visual	$2^\circ 46'$

- (c) the concentration about the mean direction of orientation was usually high, but was not homogenous within groups nor was it significantly different when large and small fish were compared. The concentration was lower for observations under non-visual conditions than for those under visual conditions. In other words there was a wider (but not-significant) distribution about the mean direction of orientation in non-visual conditions.

4 DISCUSSION

In an earlier note (Parrish, Blaxter and Dickson, 1962), based on some of the preliminary work using this underwater technique, it was tentatively concluded that orientation became reduced in non-visual conditions. The additional experiments and more detailed analysis carried out since indicate that there was, in fact, a high degree of orientation under both visual and non-visual conditions and with both large and small fish. This suggests that under non-visual conditions orientation is brought about by other stimuli produced in the vicinity of the trawl mouth. It would seem that tactile ones are the most likely. It should be noted, however, that the degree of orientation, as indicated by the concentration of the vectors about the mean direction, was generally lower in non-visual conditions, and that the two experiments in which the distribution of directions did not differ significantly from random were both carried out in non-visual conditions.

Beamish (1967), who has used an identical technique with otter trawls in the north-west Atlantic, found that haddock actually showed better orientation by night than by day, though cod showed better orientation by day. Most haddock swam between $\pm 40^\circ$ to the direction of tow. At night 56 percent swam within $\pm 10^\circ$ to the direction of tow, but only 41 percent by day.

While the main species seen in the present experiments were herring, cod, haddock and whiting, other species were observed. Mackerel (*Scomber scombrus*) (Fig. 1E) were photographed by day but were not taken by the net. Presumably they swam fast enough to escape. Sand eels (*Ammodytes* sp) (Fig. 1F) were also seen by both day and night but were not caught. Their orientation was as good by night as by day. A striking feature of the results was the absence of flat fish in the photographic records, despite their appearance, sometimes in large numbers, in the catches. The explanation of this is not clear.

With the camera in other positions few fish were photographed and there can be little doubt that this technique is most successful where fish are concentrated, as in the light of the foot rope.

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5 REFERENCES

- Beamish, F.W.H., Photographic observations on reactions of fish ahead of otter trawl.
1967 Paper presented to the FAO Conference on Fish Behaviour in Relation to
Fishing Techniques and Tactics, Bergen, 19-27 October 1967, (E/25):11 p.
- Blaxter, J.H.S. and B.B. Parrish, The reaction of marine fish to moving netting and
1966 other devices in tanks. Mar.Res., 1966(1):1-15
- Craig, R.E. and R.G. Lawrie, An underwater light intensity meter. Limnol.Oceanogr.,
1962 7(2):259-61
- Craig, R.E. and R. Priestley, Undersea photography in marine research. Mar.Res., 1963
1963 (1):24 p.
- Parrish, B.B., J.H.S. Blaxter and W. Dickson, Photography of fish behaviour in relation
1962 to trawls. ICES, Comparative Fishing Committee, C.M.Doc. (77)

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